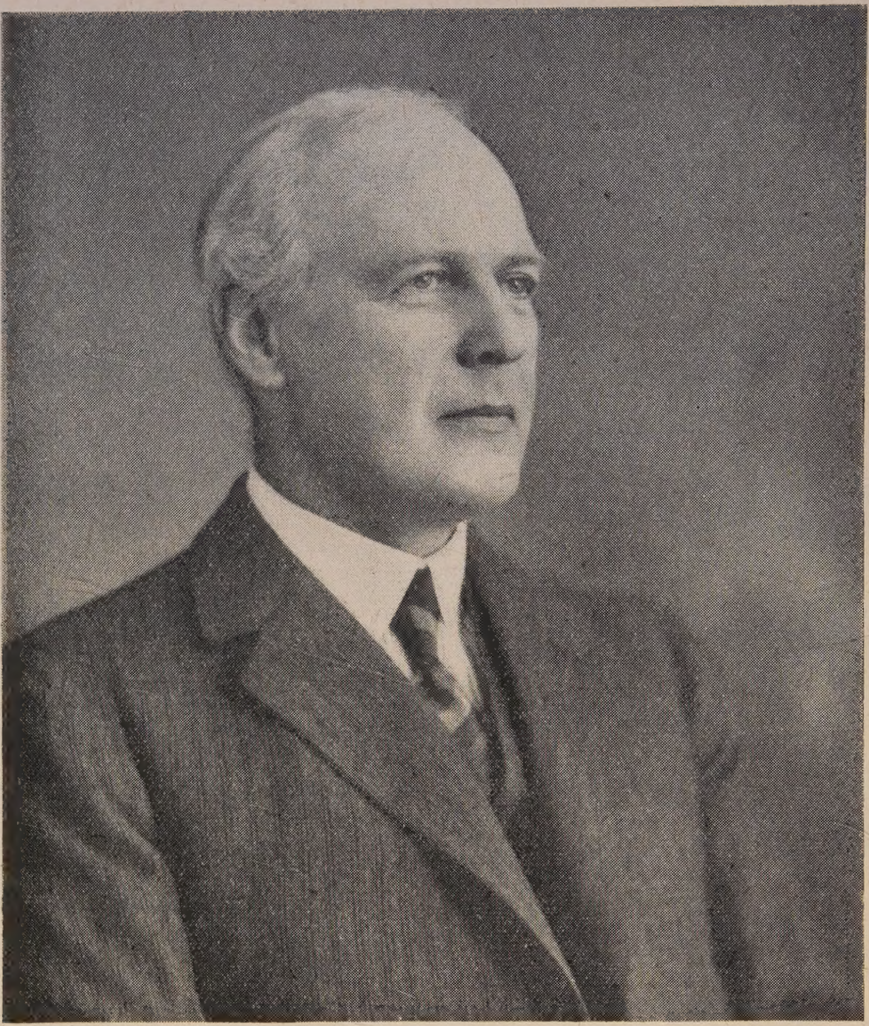

D. SHARPE,

President, 1943–44.

MR. DANIEL SHARPE has had a wide and varied experience in foundry and metallurgical work. He received his early education in various Glasgow schools, and later at what is now known as the Royal Technical College, Glasgow. He gained his practical metallurgical training in the Steel Company of Scotland, Limited, where he spent six years ; four in the laboratory and two years as steel melter and sample passer at Blochairn Works, Glasgow. Mr. Sharpe then became chemist and assistant foundry manager with the Acme Steel & Foundry Company, Limited, Shettleston, with whom he remained about two years, when he returned to the Steel Company of Scotland to become metallurgist and assistant steel foundry manager at the Hallside Works, Newton. Later Mr. Sharpe was appointed manager of the National Steel Foundry Company, Limited, at Leven, Fife, afterwards becoming a Director of the Company.

In 1920 Mr. Sharpe went to the United States of America as a consulting foundry engineer, where he spent more than a year visiting over 100 iron and steel foundries. During this visit to America Mr. Sharpe became particularly interested in the Sandslinger system of moulding, and returned to Britain to develop the European patents of this machine, a direction in which his activities were concentrated for some years.

Mr. Sharpe became a member of the Institute of British Foundrymen in 1920, and was President of the Scottish Branch in 1936 when the highly successful Annual Conference was held in Glasgow. Mr. Sharpe has delivered Papers before practically every Branch of the Institute of British Foundrymen. He is also a member of the West of Scotland Iron and Steel Institute and of the Institute of Vitreous Enamellers.

At present Mr. Sharpe is Technical Executive (Steel) to Federated Foundries, Limited, and is a director of Walter Macfarlane & Company, Limited, Saracen Foundry, Possilpark, Glasgow. He is also Chairman of A. & W. Smith & Company, Limited, Engineers and Manufacturers of Sugar Mill Machinery ; Chairman of R. G. Ross & Company, Limited, Steam and Air-Hammer Makers ; is a Director of Foundry Plant & Machinery, Limited, and of B.I.A. Patents, Limited. He is also Chairman of Sugar Machinery Association ; the Sugar Machinery Export Group, and of the Engineering Section, Glasgow Chamber of Commerce.

PROCEEDINGS
OF THE
INSTITUTE OF
BRITISH FOUNDRYMEN

VOLUME XXXVI~~I~~ 1942-1943

Volume XXXVI — 1942-1943

Containing the Papers presented to the Fortieth Annual General Meeting of the Institute and a selection of the Papers presented to the Branch Meetings held during the Session 1942-1943.

Edited by J. BOLTON, Acting Secretary

Published by the
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Saint John Street Chambers, Deansgate, Manchester, 3
(Registered Office: 49, Wellington Street, Strand, London, W.C.2)

The Institute of British Foundrymen

Founded 1904. *Incorporated by Royal Charter,* 1921

Officers, 1943-44

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D. H. Wood, " Cotswold," Barnt Green, Birmingham.

JUNIOR VICE-PRESIDENT:

J. W. Gardom, Ripley, Derbyshire.

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(Surviving Past-Presidents are ex-officio members of the Council.)

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H. Pilkington. (Deceased.) 1906–1907.
F. J. Cook, M.I.Mech.E., 31, Poplar Avenue, Edgbaston, Birmingham, 17. 1908–1909.
P. Longmuir, M.B.E., D.Met., (Deceased, 1942.) 1910-1911.
C. Jones. (Deceased, 1923.) 1912.
S. A. Gimson, J.P. (Deceased, 1938.) 1913–1914.
W. Mayer. (Deceased, 1923.) 1915.
J. Ellis. (Deceased, 1930.) 1916–1917.
T. H. Firth. (Deceased, 1925.) 1918.
John Little, M.I.Mech.E. (Deceased, 1932.) 1919.
Matthew Riddell. 1920.
Oliver Stubbs. (Deceased, 1932.) 1921.
H. L. Reason. 1922.
Oliver Stubbs. 1923.
R. O. Patterson, Pioneer Works, Blaydon-on-Tyne. 1924.
J. Cameron, J.P., Cameron & Roberton, Ltd., Kirkintilloch, Scotland. 1925.
V. C. Faulkner, F.R.S.A., 3, Amersham Road, High Wycombe, Bucks. 1926.
J. T. Goodwin, M.B.E., M.I.Mech.E., Grove Hill, Newbold Moor, Chesterfield, 1927.
S. H. Russell, Bath Lane, Leicester. 1928.
Wesley Lambert, C.B.E., 24, Caledon Road, Parkstone, Dorset. 1929.
F. P. Wilson, J.P., " Parkhurst," Middlesbrough. 1930.
A. Harley, " Ashlea," 11, East Ave., Stoke Park, Coventry. 1931.
Victor Stobie, M.I.E.E., (Deceased, 1941). 1932.
C. E. Williams, J.P., " Coniston," Cefn-Coed Road, Roath Park, Cardiff. 1933.
Roy Stubbs, 36, Broadway, Cheadle, Cheshire. 1934.
J. E. Hurst, J.P., D.Met., " Ashleigh," Trent Valley Road, Lichfield, Staffs. 1935.
H. Winterton, " Moorlands," Milngavie, Dumbartonshire. 1936.
C. W. Bigg, " Selworthy," Burley Lane, Quarndon, near Derby. 1937.
J. Hepworth, J.P., M.P., " Woodhall Grange," Woodhall Hills, Calverley, nr. Leeds. 1938.
W. B. Lake, J.P., Albion Works, Braintree, Essex. 1939–1940.
Major R. Miles, M.Eng., Teesdale Ironworks, Thornaby-on-Tees. 1941-1942

HON. TREASURER:

S. H. Russell, Bath Lane, Leicester.

SECRETARY:

T. Makemson, Assoc.M.C.T.

ACTING SECRETARY AND GENERAL OFFICE:

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Registered Office : 49, *Wellington Street, Strand, London, W.C.2.*

AUDITORS

Messrs. J. & A. W. Sully & Co., Parliament Mansions, Abbey Orchard Street, Victoria Street, London, S.W.1.

COUNCIL.

Delegates Elected at Annual General Meeting

H. Bunting, 11, North Avenue, Darley Abbey, nr. Derby.
L.W.Bolton, A.M.I.Mech.E., British Cast Iron Research Association, Alvechurch, Birmingham.
V. Delport, 2, Caxton Street, Westminster, London, S.W.1.
A. B. Everest, Ph.D., B.Sc., Mond Nickel Co., Ltd., Grosvenor House, Park Lane, London, W.1.
Barrington Hooper, C.B.E., 3, Amersham Road, High Wycombe, Bucks.
E. Longden, M.I.Mech.E., 11, Welton Avenue, Didsbury Park, Manchester, 20.
F. K. Neath, B.Sc., Hollywell House, Armley, Leeds, 12.
A. Phillips, 1, Melfort Avenue, off Edge Lane, Stretford, Manchester.
P. A. Russell, B.Sc., Bath Lane, Leicester.
R. B. Templeton, "White Cottage," Denham, Bucks.

Branch Delegates.

(*Branch represented shown in brackets.*)

R. Ballantine, "Duncruin," North St., Motherwell, Lanark (Scottish).
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C. C. Booth, J.P., Mildmay Ironworks, Burnham-on-Crouch, Essex. (London).
W. Y. Buchanan, "Dunconnell," Thomson Avenue, Johnstone, Renfrewshire (Scottish).
F. G. Butters, Hallam House, Bramshall Road, Uttoxeter, Staffs. (East Midlands).
W. N. Cook, B.Sc., 10, Stanley Road, Heaton Moor, Stockport (Lancs).
T. H. Gameson, T. Gameson & Sons, Ltd., Britannia Foundry, Lower Rushall Street, Walsall, Staffs. (Birmingham).
W. Holland, 24, Tresco Avenue, Kings Road, Edge Lane, Stretford, Manchester (Lancs).
J. Jackson, Howard & Bullough, Ltd., Accrington, Lancs (Lancs).
C. H. Kain, Lake & Elliot, Ltd., Albion Works, Braintree, Essex (London).
B. B. Kent, Cerne Easter, Westerham, Kent (London).
A. L. Key, 35, Longmead Road, Pendleton, Salford, 6 (Lancs).
J. E. Mercer, "Garden Well," Thornton, Stainton-in-Cleveland, near Middlesbrough (Middlesbrough).
N. P. Newman, "The Halt," Amberley, Glos. (Bristol).
R. F. Orme, "Hallworth," Hinckley Road, Leicester Forest East, Leicester (East Midlands).
A. E. Peace, "Caerhayes," Evans Avenue, Allestree, Derby (East Midlands).
W. H. Salmon, Assoc. Met., 38, Glebe Rd., Crookesmoor, Sheffield, 10 (Sheffield).
G. R. Shotton, 45, Vicarage Road, Smethwick, Staffs. (Birmingham).
J. N. Simm, 61, Marine Drive, Monkseaton, Northumberland (Newcastle).
F. E. Steele, 130, Birley Moor Road, Frecheville, Sheffield (Sheffield).
W. G. Thornton, "Riverslea," Cottingley Bridge, Bingley, Yorks. (W.R. of Yorks.).
T. Tyrie, B.Sc., Foundry Technical Institute, Meeks Road, Falkirk (Scottish).
W. Williams, Alexandra Brass Foundry, East Dock, Cardiff (Wales and Monmouth).
A. S. Worcester, 162, Victoria Road, Lockwood, Huddersfield (W.R. of Yorks).

J. G. Pearce, M.Sc., M.I.E.E., M.I.Mech.E., F.Inst.P., Alvechurch, Birmingham.

Branch Presidents and Hon. Branch Secretaries.

(*Ex-officio Members of Council.*)

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A. A. Timmins, F.I.C., 33, Carter Lane, Quinton, Birmingham, 32.

BRISTOL.

F. Jackson, "Brinkworth," Thrupp Lane, near Stroud, Glos.
A. Hares, 20, Greenbank Road, Hanham, Bristol.

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W. H. Smith, "Ryton," Grange Avenue, Normanton, Derby.
S. A. Horton, "Three," Mostyn Avenue, Littleover, Derby.

LANCASHIRE.

E. J. L. Howard, "Apsleydene," Altrincham Road, Wilmslow Cheshire.
H. Buckley, "Ellesmere," Norfolk Avenue, Burnley, Lancs.

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V. C. Faulkner, 3, Amersham Road, High Wycombe, Bucks.

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J. K. Smithson, North Eastern Iron Refining Co., Ltd., Stillington, Stockton-on-Tees.

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C. Lashly, M.C., Close Works, Gateshead-on-Tyne.

SCOTTISH.

D. H. Young, 20, Balgonie Road, Mosspark, Glasgow, S.W.2.
J. Bell, 60, St. Enoch Square, Glasgow, C.1.

SHEFFIELD.

C. J. Dadswell, Ph.D., B.Sc., 3, Denbank Avenue, Sheffield, 10.
T. R. Walker, M.A., 11, Broomgrove Crescent, Sheffield, 10.

SOUTH AFRICAN.

J. M. Stones, c/o J. H. Ritchie & Co., P.O. Box 4720, Langlaagate Johannesburg.
B. P. Skok, P.O. Box 1338, Johannesburg.

WALES AND MONMOUTH.

H. J. V. Williams, John Williams & Sons (Cardiff), Ltd., Globe Foundry, East Moors Road, Cardiff.
A. S. Wall, 14, Palace Avenue, Llandaff, Cardiff.

WEST RIDING OF YORKSHIRE.

L. Turner, 5, Waverley Road, Elland, Yorks.
D. Jepson, M.Sc., 9, Ambleside Road, Toller Lane, Bradford.

Section Presidents and Hon. Section Secretaries.

These sections are part of the Branches with which they are associated. The following officers are invited to attend Council Meetings.

EAST MIDLANDS—LINCOLN SECTION.

J. H. Bingley, Newark Road, North Hykeham, Lincoln.
E. R. Walter, Ph.D., M.Sc., Technical College, Lincoln.

LANCASHIRE—BURNLEY SECTION.

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A. N. Sumner, Ranelagh Works, Ipswich, Suffolk.

SCOTTISH—FALKIRK SECTION.

J. S. Kidd, "Roseburn," Burnside Terrace, Camelon, Falkirk.
T. R. Goodwin, 126, Main Street, Bonnybridge, Stirlingshire.

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AUSTRALIA: W. T. Main, T. Main & Sons (Pty.), Ltd., Lambert Street, Richmond, E.1, Victoria, N.S.W
SOUTH AFRICA: A. H. Moore Standard Brass Foundry, Benoni, Transvaal.

AWARDS 1942-43

THE "OLIVER STUBBS" GOLD MEDAL

1943 Award to Mr. C. H. Kain, in recognition of the value of the many papers which he has presented to the Institute, his long service as a member of the Technical Committee and his Convenership of the Steel Castings Sub-Committee and of his services on the General Council of the Institute and a number of standing committees.

The Oliver Stubbs Medal has been awarded as follows:—

1922.—F. J. Cook, M.I.Mech.E.
1923.—W. H. Sherburn.
1924.—John Shaw.
1925.—A. Campion, F.I.C.
1926.—A. R. Bartlett.
1927.—Professor Emeritus Thomas Turner, M.Sc.
1928.—J. W. Donaldson, D.Sc.
1929.—Wesley Lambert, C.B.E.
1930.—James Ellis.
1931.—John Cameron, J.P.
1932.—J. E. Hurst, D.Met.
1933.—J. W. Gardom.
1934.—V. C. Faulkner.
1935.—No Award.
1936.—F. Hudson, E. Longden } Two Awards.
1937.—P. A. Russell, B.Sc.
1938.—S. E. Dawson, F.I.C.
1939.—J. G. Pearce, M.Sc., M.I.E.E., M.I.Mech.E., F.Inst.P.
1940.—A. E. Peace.
1941.—J. J. Sheehan, A.R.C.Sc.I., A.I.C.
1942.—S. H. Russell.
1943.—C. H. Kain.

THE MERITORIOUS SERVICES MEDAL

The 1943 Award to Mr. A. Hares, Honorary Secretary of the Bristol and West of England Branch. Mr. Hares was largely responsible for the formation in 1936 of the Bristol Section of the Wales and Monmouth Branch and for the development of this Section, which led to the granting to it of Branch status in January, 1943.

The Meritorious Services Medal has been awarded as follows:—

1933.—F. W. Finch.
1934.—J. J. McClelland.
1935.—H. Bunting.
1936.—J. Smith.
1937.—No Award.
1938.—No Award.
1939.—J. E. Cooke.
1940.—J. Bell.
1941.—H. W. Lockwood.
1942.—S. W. Wise.
1943.—A. Hares.

THE "E. J. FOX" GOLD MEDAL

The 1943 Award was made to Mr. W. B. Lake, J.P., in recognition of his outstanding contributions to the development of the foundry industry. (Mr. Lake's pioneer achievements are recorded more fully in the account of the 1943 Annual Meeting.)

The E. J. Fox Gold Medal has been awarded as follows:—

1937.—Professor Emeritus Thomas Turner, M.Sc.
1938.—J. E. Hurst, D.Met.
1939.—Dr. Harry A. Schwartz.
1940.—W. J. Dawson.
1941.—P. Pritchard.
1942.—P. H. Wilson, O.B.E., M.I.Mech.E.
1943.—W. B. Lake, J.P.

DIPLOMAS OF THE INSTITUTE

were awarded to:—

Mr. J. BLAKISTON, for his Paper on "The Substitution of High-Duty Grey Cast Iron for Steel Castings," presented to the Annual Meeting 1942.

Mr. L. W. BOLTON and Mr. J. HILL, joint authors of a Paper on "The Continuous Production of Manganese Steel Castings for the Tropenas Converter."

Mr. W. BROWN, for his Paper on "Essential Points in the Production of Non-Ferrous Castings," presented to the Lancashire Branch.

Mr. F. DUNLEAVY, for his Paper on "Foundry Technique in Relation to Certain Pressure Castings," presented to the Lancashire Branch.

Mr. W. GLADWELL, for his Paper on "Radiography as an Aid to Foundry Technique," presented to the London Branch.

Mr. R. HORTON, joint author with Mr. G. L. Harbach, for his Paper on "Industry and Education."

Mr. J. McPHEAT and Mr. J. Arnott, for his joint Paper with Mr. F. B. Ling, on "The Spectrographic Analysis of Cast Iron."

Mr. W. MONTGOMERY, for his Paper on "Acid Resistance and Technical Control in an Enamelling Plant," presented to the Scottish Branch.

Mr. L. W. SANDERS, joint author with Mr. C. H. Kain, of a Paper on "Production of Uniform Steel for a Light Castings Foundry," presented to the Annual Meeting, 1942.

Mr. J. VICKERS, joint author with Mr. B. MacDougall, of a Paper on "Aero Engine Castings," presented to the Scottish Branch.

Mr. H. G. WARRINGTON, for his Paper on "A Method of Correlating Foundry Production and Quality of Light Alloy Castings."

THE "EDWARD WILLIAMS" LECTURE

The following Lectures have now been delivered :—

1935.—" Man and Metal " (delivered at Sheffield)—Sir William J. Larke, K.B.E.

1936.—" Cast Iron and the Engineer " (delivered at Glasgow)—Prof. A. L. Mellanby, LL.D., D.Sc.

1937.—" Factors in the Casting of Metals " (delivered at Derby)—C. H. Desch, D.Sc., Ph.D., F.R.S.

1938.—Not delivered.

1939.—" The Atomic Pattern of Metals " (delivered in London)—Prof. Sir Lawrence Bragg, O.B.E., M.C., D.Sc., M.A., F.R.S.

1940.—Not delivered.

1941.—Not delivered.

1942.—" Foundry Teamwork " (delivered in London)—Dr. H. W. Gillett. (The lecture was delivered on behalf of the author by J. G. Pearce, M.Sc., F.Inst.P.).

1943.—" The Contribution of the Steel Founder to Marine Engineering " (delivered in London)—S. F. Dorey, D.Sc.

SPECIAL REPORTS

The following special reports have been published by the Institute, but are not included in the Annual Volume of " Proceedings." Copies are available on application to the Secretary.

Special Report No. 1.—" The Properties of Grey Cast Iron with Special Reference to the British Standards Specifications," by the Cast Iron Sub-Committee of the Technical Committee. September, 1938.

Special Report No. 2.—" Melting Furnaces for Grey Cast Iron," by the Melting Furnaces Sub-Committee of the Technical Committee, January, 1940.

Special Report No. 3.—" Fuel Economy in Foundries." Recommendations of the Technical Committee. May, 1943.

Special Report No. 4.—" The Workshop Training and the Education of Young Foundrymen." Memorandum by the Education Committee. November, 1943.

The following are also available on application to the Secretary :—

" Reclamation of Porous Non-Ferrous Castings," by the Non-Ferrous Sub-Committee of the Technical Committee. September, 1943.

" Recommendations Concerning the Establishment of Costs in a Grey Iron Foundry," by the Costing Sub-Committee of the Technical Committee. Reprint, with revisions, of Paper No. 606 (see " Proceedings," Vol. XXX, 1936–37, p. 100).

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The Institute of British Foundrymen

ANNUAL GENERAL MEETING

The fortieth annual general meeting of the Institute of British Foundrymen was held at the Waldorf Hotel, London, on Saturday, June 26, Major R. Miles, M.Eng., the President, in the chair. The minutes of the annual general meeting held in London on June 20, 1942, were taken as read and were confirmed and signed.

Report of Council

The Report of the Council for 1942-43 was presented, the President drawing attention to the satisfactory financial position and to a substantial increase in membership during the year. He also mentioned the establishment of the British Foundry Medal and said that the two paragraphs in the Report dealing with "Branch Activities" very modestly recorded a great deal of work which had been done, often at the sacrifice of time and leisure by the Branch officers, to whom he expressed the gratitude of the Council and members, whose thanks also were due to the continued efficiency and courtesy of the secretarial staff. Mr. Makemson would probably endorse a special reference to Mr. Bolton, the acting secretary. The President then moved the adoption of the Report. (See page 3.)

Mr. V. C. Faulkner said it gave him much pleasure to second the adoption of a Report which was excellent in every respect. The Report was unanimously adopted without discussion.

Accounts

Mr. S. H. Russell (Hon. Treasurer), presenting the Balance Sheet at December 31, 1942, and the Statement of Accounts for the year ended December 31, 1942, and moving their adoption, said it would be agreed that the financial position was very satisfactory. There had been another record increase in the membership and the total receipts from subscriptions were £3,339 against £3,238. Interest on investments and deposits at the bank went up to £133 against £98. Turning to the expenditure side of the Income and Expenditure Account, he said the excess of income over expenditure was £708 against £864 in the previous year, and members might wonder why, in spite of an increased income, the balance was less. This was mainly due to increased activity in several departments of the Institute. The Branch expenses had gone up practically everywhere and so had other expenses and he felt it was the right policy to spend money in this way in the interests of the work of the Institute. Five years ago they were getting worried because it did not appear that the income would meet the expenditure but that position had now been reversed.

Mr. W. B. Lake seconded the motion for the adoption of the Accounts. There were no questions and the motion was carried unanimously.

Report of the Technical Committee

Mr. J. W. Gardom, Convener of the Technical Committee, in presenting the 11th Annual Report of this Committee, said that apart from what was stated in the annual report of the Council, in the report of the Technical Committee there was a point he wished to mention and that was the attendance of the representatives of the Technical Committee on the technical committees of external associations and the British Standards Institution. The latter had just decided to appoint a further Committee known as ME 22 to consider the standardisation of moulding boxes, sand testing equipment, etc. During the past year some members of the Institute had been asked to give information with regard to silicosis, but, unfortunately, it had not been found possible to proceed with that enquiry. Everyone would receive a communication and the details supplied would be given in the next Report. As regards fuel economy in foundries, there might have been criticisms of this campaign, but personally he regarded the special report which had been issued to members as one of the best efforts of the Committee, and it was prepared in three meetings, which must be a record for this sort of work. He thanked all those who had assisted in this. It had been said that foundries were doing all that was recommended, but he assured the members that every foundry was not doing it, and somebody would call on them and show them where they were not doing it and how it should be done. He moved the adoption of the Report.

Mr. P. A. Russell, B.Sc. (Deputy Convener), seconded the adoption of the Report. The Report was unanimously adopted, the President remarking that the Committee had done extremely good work especially during the war years.

Oliver Stubbs Gold Medal

The President said the Council had decided to award this medal to Mr. C. H. Kain. Mr. Kain became a member of the London Branch in 1927. He had presented many Papers to the Institute and was the author of the official exchange Paper to the American Foundrymen's Association in 1942. He was a past-President of the London Branch and had been awarded a Diploma. Many of his Papers contained the results of original research. He was elected Convener of the Steel Castings Sub-Committee of the Technical Committee in 1935 and had held that office ever since. The medal was then presented to Mr. Kain.

Mr. C. H. Kain said that any success he might have had in the affairs of the Institute was due entirely to two things. The first was the necessity for keeping up with the very rapid pace set by his chief, Mr. Lake, and the second was the help he had had from his colleagues at Braintree, and especially his colleagues on the Council of the London Branch who had the very happy knack of making the work of the Institute something worth while and not something apart.

The E. J. Fox Gold Medal

The President said that, on the recommendation of the assessors, the Council had unanimously resolved to award the E. J. Fox Gold Medal for 1943 to Mr.

W. B. Lake (loud applause). In making their recommendation to the Council the assessors had written:—

> "Mr. W. B. Lake, J.P., is Chairman and Managing Director of Lake & Elliot, Limited, Braintree, and a man whose work as an industrialist has contributed in an outstanding manner to the progress of the foundry industry. As a pioneer in the develop- of the industry, Mr. Lake can claim to be the—
>
> First to instal low carbon, crucible steel castings, 1907.
>
> First to instal an Electric Arc Furnace for steel castings, 1910.
>
> First to introduce Synthetic Green Moulding Sand into Steel Foundry, 1917.
>
> First to instal Sand Slinger in Steel Foundry, 1923.
>
> First to produce Malleable Castings from the Electric Furnace, 1924.
>
> First to instal a High Frequency Furnace for Steel Castings, 1928.
>
> First to produce Special and Alloy Cast Iron in the High Frequency Furnace, 1929.
>
> Mr. Lake was also a very outstanding and popular President of the Institute during the last International Convention, which was held in London in 1939, also a Past Treasurer of the Institute."

In asking Mr. Fox to make the presentation, he expressed thanks to him for continuing to display his interest in the Institute by attending personally to make this presentation.

MR. E. J. FOX said it was doubtful whether there was anybody in this country who had done so much for foundry practice generally as Mr. Lake, and particularly had he assisted in establishing the Institute on really solid foundations. If only for these reasons, everybody was delighted and welcomed Mr. Lake after his illness.

The Medal and Certificate were presented to Mr. Lake.

MR. W. B. LAKE said that when, in 1939, he had the privilege of presenting this medal to Dr. Schwartz of Cleveland, it never occurred to him then or at any time after that he would one day be the recipient of that honour. When, therefore, he was told that it was to be awarded to himself this year, the news gave him one of the greatest and most pleasant surprises of his life. He considered it a very high honour for his name to be added to the list of those distinguished men who had previously received the medal. Some kind and too flattering references had been made to the contribution of himself to the progress in the foundry industry, but he would like to say that any success he had achieved was largely due to the men who had helped him. That they were prominent in the Institute was no coincidence, because for many years all the most progressive technicians in the foundry industry had been members of the Institute of British Foundrymen.

In the early days of crucible melting, and later with the electric furnace, he received great help from the late Daniel Wilkinson. Later he received valuable assistance from Fred Melmoth, now vice-president of the Detroit Steel Castings Company, and Dan Sharpe, President-Elect of the Institute, whilst Colin Kain was now continuing very efficiently the work of his predecessors. Personally, he felt very greatly indebted to these men for the honour that had now been conferred upon him. He thanked Mr. Fox for the kind words he had used in making this presentation, and assured him that to receive the medal from his hands added to his own pleasure in receiving it. He also thanked the members for their cordial reception and expressed regret that indifferent health had obliged him to miss so many meetings, but he assured them that he was, and always would be, deeply grateful for the many kindnesses they had shown him during his long and happy association with the Institute.

Meritorious Services Medal

The PRESIDENT, announcing that the Council had awarded this medal this year to Mr. A. Hares, said that he had been a very active member of the Institute ever since his election as a member in 1927. It was largely due to his efforts that a Section of the Wales and Monmouth Branch was established at Bristol in 1936, and of this Section Mr. Hares became honorary secretary. During the last seven years he had done much towards promoting the objects of the Institute in the West of England area, thus increasing the importance and membership of the Bristol Section, which, at the beginning of this year, was granted Branch status by the Council. Mr. Hares remained honorary secretary of the Branch. The medal was then presented.

MR. HARES said he regarded the award of this medal not only as an appreciation of his services to the Bristol and West of England Branch—and his own work had not been so very hard—but also as an appreciation of the close co-operation of his Branch Council, whose object was always to further the interests of the Institute throughout the south-west.

Diplomas

The SECRETARY (Mr. Makemson) announced the award of Diplomas to the following, and said they would be handed to the various recipients in due course at the Branches.

J. Vickers, joint author, with B. MacDougall, of a Paper on "Aero Engine Castings."

F. Dunleavy for a Paper on "Foundry Technique in Relation to Certain Pressure Castings."

W. Montgomery for a Paper on "Acid Resistance and Technical Control in Enamelling Plants."

W. Gladwell for a Paper on "Radiography as an Aid to Foundry Technique."

W. Brown for a Paper on "Essential Points in the Production of Non-ferrous Castings."

Establishment of the British Foundry Medal

The PRESIDENT announced that Mr. Barrington Hooper, C.B.E., and the proprietors of the "Foundry Trade Journal," had very generously offered to provide annually a medal for presentation to the author of the best Paper presented to the Institute each year. The Council had had very much pleasure in accepting this munificent offer of Mr. Hooper and his company and, in collaboration with the donor, had drawn up rules to govern the award. The rules were printed in the Report. He asked the members to endorse the Council's gratitude and to show their appreciation.

ELECTION OF OFFICERS

President

The PRESIDENT, on behalf of the Council, proposed that Mr. Daniel Sharpe, Junior Vice-President, be elected President for the year 1943-44. Continuing, he said that Mr. Sharpe had had a wide and varied experience in foundry and metallurgical work. He gained his practical metallurgical training with the Steel Company of Scotland. Later he was appointed manager of the National Steel Foundry Company, Limited, at Leven, Fife, afterwards becoming a director of the company. In 1920, Mr. Sharpe went to the United States of America as a consulting foundry engineer, where he spent more than a year visiting over 100 iron and steel foundries. During this visit Mr. Sharpe became particularly interested in the Sandslinger system of moulding and returned to Britain to develop the European patents of this machine. Mr. Sharpe was President of the Scottish Branch in 1936, when the highly successful Annual Conference was held in Glasgow. At present Mr. Sharpe was Technical Executive (Steel) to Federated Foundries, Limited, and a director of Walter Macfarlane & Company, Limited, Saracen Foundry, Possilpark, Glasgow, and of numerous other concerns.

MR. H. WINTERTON seconded the motion and said it had the support of the members of the Scottish Branch with whom Mr. Sharpe was very popular.

THE PRESIDENT, in putting the motion to the meeting, said that a welcoming telegram had been received from the Scottish Branch. The proposal was carried enthusiastically, and Mr. Sharpe was inducted into the chair, but afterwards asked Major Miles to continue to preside until the end of the meeting.

MR. SHARPE said he would try and live up to all the kind things that had been said about him. The annals of the history of the Institute contained many honoured names, not the least of which would be that of the retiring President, Major Miles, to whom he asked the members to express appreciation of his services during the past two years. There were few Presidents who had shown more activity.

The vote of thanks was given with hearty acclamation.

The retiring PRESIDENT expressed his appreciation of the vote of thanks and said it had been with a certain amount of reluctance that he had been able to take on the office of President for a second year. Now, however, he found almost more reluctance in giving the job up because the work had been so pleasurable.

Senior Vice-President

MR. F. J. COOK said it gave him great pleasure to propose the re-election of Mr. D. H. Wood as Senior Vice-President and added that he was perfectly certain that when Mr. Wood took over the office of President, which he understood was to be as soon as the war was over, he would have the support of every member.

MR. C. W. BIGG seconded the motion, which was carried unanimously.

MR. D. H. WOOD said he greatly appreciated the fact that he had again been elected Senior Vice-President. It was the decision of the Council two years ago that he should be put into cold storage until after the war, but he felt a little diffident in holding this office for the fourth year, as he was keeping a better man out of a job. However, as it was the wish of the Council and of the members, he would do his best for the Institute until such time as it was thought fit to displace him.

Junior Vice-President

MR. D. H. WOOD proposed the election of Mr. J. W. Gardom as Junior Vice-President, on the recommendation of the Council. He said it would not be an exaggeration to say that during the past three years Mr. Gardom had done as much as, if not more than, anybody to increase the production of vitally needed castings, particularly those required for tanks and munitions. In his capacity as chairman of the Technical Committee for some twelve years, he had been responsible for an enormous amount of work, and he doubted whether 2 per cent. of the members of the Institute could attempt to keep up with the pace Mr. Gardom set. He had every confidence in submitting Mr. Gardom's name and hoped that, when in due course he occupied the presidential chair, others of them would not be found among the "also rans"!

DR. J. E. HURST seconded the motion, and said he knew Mr. Gardom well enough to be able to recommend him. He knew a great deal about him, but nothing that did not qualify him from ultimately occupying the presidential chair. The motion was carried with enthusiasm.

MR. GARDOM, acknowledging his election, said it was 21 years almost to the day that he joined the Institute at the time he first became associated with foundry production, but he almost felt that his election as Junior Vice-President was a wrench from the back-benchers with whom he had worked so long.

Election of Auditors and Council Members

On the motion of MR. H. W. LOCKWOOD, seconded by DR. A. B. EVEREST, Messrs. J. & A. W. Sully & Company were re-elected auditors for the ensuing year.

The SECRETARY announced the result of the ballot for five vacancies on the Council, as follows:—L. W. Bolton, V. Delport, Barrington Hooper, E. Longden and P. A. Russell. To fill the vacancy caused by the election of Mr. Gardom as Junior Vice-President, it was agreed to elect Mr. R. B. Templeton, the next on the ballot list, for one year, following the usual practice.

Council of Ironfoundry Associations

MR. S. H. RUSSELL proposed, and MR. C. H. KAIN seconded, a motion that Major Miles be elected the Institute's representative on the Council of Ironfoundry Associations. The motion was carried unanimously.

MAJOR MILES said he regarded this as a great honour, because for the first time the whole of the ironfoundry trade seemed to be getting together, and that had been due almost entirely to the energy and organising ability of Mr. FitzHerbert Wright.

Presidential Address

MR. D. SHARPE then took the chair and delivered his presidential address. (See page 10.)

Edward Williams' Lecture

Following the Presidential Address, Dr. S. F. Dorey, Chief Engineer Surveyor, Lloyd's Register of Shipping, presented the sixth Edward Williams' Lecture, entitled "The Contribution of the Steel Founder to Marine Engineering." (See page 12.)

Technical Session

In the afternoon three technical sessions were held simultaneously, one devoted to non-ferrous subjects, one to ironfounding, and one—a joint meeting with the Iron and Steel Institute—to steelfounding. The papers presented and the discussions which followed will be found on page 21. *et seq.*

40th ANNUAL REPORT

This report covers the period May 1, 1942, to April 30, 1943. The statement of accounts for the year ended December 31, 1942, and the balance-sheet at that date are also included.

Finance

The subscription revenue for the year again shows an increase over preceding years, and the expenditure is also higher than in 1941, mainly due to the increased activities of the Institute and the larger number of members for which it now caters. It has been possible, however, again to transfer a substantial credit balance to the accumulated fund.

Owing to the delays in the mail, it has not been possible to include in the balance-sheet and income and expenditure account the full accounts of the South African Branch for 1942. There is, however, included in the balance-sheet the sum of £52 1s. 4d.

in the hands of the South African Branch Secretary at December 31, 1941, which amount was transferred to the general office during 1942, together with the sum of £50 on account of 1942 subscriptions. These two amounts totalling £102 1s. 4d. are shown as income in the income and expenditure account for 1942.

Membership

The present position of the membership and the changes which have taken place during the year are recorded in Tables I and II, and it will be noted that there has been a very satisfactory increase in the last twelve months.

The apparent decline in the membership of the Wales and Monmouth Branch is accounted for by the granting by the Council of Branch status to the Bristol Section of that Branch, to which further reference is made under "Branch Activities." It will be noted that the combined membership total for the two Branches is now 186, as against 125 at April 30, 1942.

TABLE I.—*Changes in Membership*, 1942–1943

	Subscribing firms.	Members.	Associate members.	Associates.	Associates (students).	Totals.
At April 30, 1942	80	1,008	1,180	98	41	2,407
Additions and transfers from other grades ..	17	129	174	6	5	331
	97	1,137	1,354	104	46	2,738
Losses and transfers to other grades	1	44	60	21	10	136
At April 30, 1943	96	1,093	1,294	83	36	2,602

It is particularly gratifying to record that there are now more than 400 members attached to the London Branch, and the Council congratulate the Branch on the very satisfactory progress which has been made.

It is with regret that the Council records the death of the following members:—

Mr. E. M. Boote, Member, Lancashire Branch. Elected 1912.

Mr. J. H. Booth, Member, East Midlands Branch. Elected 1919.

Mr. J. H. Cole, Member, Wales and Monmouth Branch. Elected 1939.

Mr. R. Kidston, Member, Lancashire Branch. Elected 1936.

Dr. P. Longmuir, M.B.E., a Founder Member of the Institute. Elected in 1904 and elected an Honorary Life Member in 1936. Past-President of the Institute; Past-President of the Sheffield Branch.

Mr. N. McManus, M.B.E., Member, Scottish Branch. Elected 1930.

Mr. J. McClure Renwick, Member, South African Branch, formerly of the London Branch. Elected 1933.

Mr. H. H. Bennett, Associate Member, Wales and Monmouth Branch. Elected 1933.

Mr. T. N. Goodwin, Associate Member, Scottish Branch. Elected 1933.

Mr. W. Hughes, Associate Member, East Midlands Branch. Elected 1938.

Mr. H. Kirkland, Associate Member, East Midlands Branch. Elected 1941.

Mr. D. Lewis, Associate Member, Birmingham Branch. Elected 1919.

Mr. J. N. McArthur, Associate Member, Scottish Branch. Elected 1928.

Mr. W. D. McCrone, Associate Member, South African Branch. Elected 1939.

Mr. J. Ross, Associate Member, Scottish Branch. Elected 1937.

Mr. W. Taylor, Associate Member, West Riding of Yorkshire Branch. Elected 1927.

Mr. E. Nelson, Associate, Newcastle Branch. Elected 1942.

The Council also records the deaths of the following three members, which took place earlier than 1942, but which have not previously been reported:—

Mr. W. L. Graham, Member, Birmingham Branch. Elected 1938.

Mr. T. Blackadder, Associate Member, Scottish Branch. Elected 1928.

Mr. M. D. Doulton, Associate, London Branch. Elected 1928. Killed in action in August, 1940.

TABLE II.—*Analysis of Membership at April* 30, 1943.

Branch.	Subscribing firms.	Members.	Associate members.	Associates.	Associates (students).	Totals.
Birmingham	12 (9)	167 (164)	149 (155)	15 (15)	5 (4)	348 (347)
Bristol	4 (—)	45 (—)	42 (—)	1 (—)	— (—)	92 (—)
East Midlands	6 (5)	81 (83)	157 (140)	4 (3)	2 (1)	250 (232)
Lancashire	15 (13)	131 (122)	212 (199)	17 (20)	1 (2)	376 (356)
London	15 (10)	237 (215)	149 (134)	2 (3)	— (—)	403 (362)
Middlesbrough	1 (1)	36 (34)	51 (48)	6 (6)	12 (15)	106 (104)
Newcastle	6 (6)	25 (28)	17 (18)	21 (30)	5 (7)	74 (89)
Scottish	8 (7)	106 (96)	213 (194)	2 (4)	2 (4)	331 (305)
Sheffield	6 (6)	84 (83)	80 (62)	2 (2)	— (—)	172 (153)
Wales & Monmouth	— (3)	40 (54)	45 (59)	— (1)	9 (8)	94 (125)
W.R. of Yorks	7 (4)	68 (61)	112 (104)	4 (4)	— (—)	191 (173)
South African	15 (15)	50 (50)	50 (48)	9 (10)	— (—)	124 (123)
Unattached	1 (1)	23 (18)	17 (19)	— (—)	— (—)	41 (38)
TOTALS	96 (80)	1,093 (1,008)	1,294 (1,180)	83 (98)	36 (41)	2,602 (2,407)

Figures in brackets are totals at April 30, 1942.

Mr. R. Sutcliffe, Associate Member of the Birmingham Branch, who was serving in the Forces at Singapore, has been reported missing. Mr. J. S. Ferguson, Associate Member, resident in Hong Kong, was taken prisoner while serving with the Hong Kong Volunteer Defence Corps. Capt. P. B. Lake, Associate Member, is a prisoner of war in Italian hands.

Seventy-six members are now serving in H.M. Forces.

Honours Conferred upon Members

The following are amongst those who have been honoured during the past year:—

Mr. Summers Hunter, J.P. (Member) was knighted in the New Year's Honours list.

Mr. P. H. Wilson (Member) was a recipient of the O.B.E. in the New Year's Honours list.

Squadron-Leader R. B. Newton (Associate Member) was awarded the Distinguished Flying Cross.

Acting Squadron-Leader S. P. Russell (Associate Member) was awarded the Distinguished Flying Cross.

Col. C. A. B. Lindop, J.P. (Member) was appointed Deputy Lieutenant of the County of Staffordshire.

Mr. W. Scott (Member) was appointed a magistrate of Jarrow.

Mr. A. Turner (Member) was appointed a magistrate of the County Borough of West Bromwich.

Dr. Andrew M'Cance (Member) was elected a Fellow of the Royal Society.

Mr. A. J. Murphy, M.Sc. (Member) was elected a Vice-President of the Institute of Metals.

Mr. F. A. Melmoth (Member) was elected Chairman of the Detroit Chapter of the American Foundrymen's Association.

Awards

E. J. Fox Gold Medal.—On the recomendation of the Assessors, Sir W. J. Larke and Dr. J. E. Hurst, the E. J. Fox Gold Medal for 1942 was awarded to Mr. P. H. Wilson, assistant managing director (technical), The Stanton Ironworks Company, Limited, near Nottingham, for his work in the development of the centrifugal casting process in the production of cast-iron pipes. The presentation was made to Mr. Wilson by Mr. E. J. Fox at the annual meeting of the Institute held in London on June 20, 1942.

The Council have re-elected Sir Wm. J. Larke and Dr. J. E. Hurst as Assessors for the E. J. Fox Gold Medal for a further period of three years.

Oliver Stubbs Gold Medal.—The Council unanimously awarded the Oliver Stubbs Gold Medal for 1942 to Mr. S. H. Russell, Past-President and Honorary Treasurer, in acknowledgment of the educational work which he had undertaken for many years as Chairman of the City and Guilds of London Institute Advisory Committee in connection with foundry technical education; the contributions which he has made to the discussions on Papers at Branch meetings; his work as Honorary Treasurer of the Institute, and his chairmanship of the Organisation Committee responsible for drafting the proposed new rules.

Meritorious Services Medal.—The Meritorious Services Medal for 1942 was awarded to Mr. S. W. Wise, Honorary Secretary of the West Riding of Yorkshire Branch. Mr. Wise served as Registrar and later as Vice-President of the Newcastle Branch; he transferred to the West Riding of Yorkshire Branch in 1923 when he became Honorary Secretary of that Branch, which position he still holds.

Diplomas.—Diplomas were awarded to the following members during the year: Mr. A. B. Bill (East Midlands Branch), Mr. F. G Butters (East Midlands Branch), Mr. E. J. Kelly (Wales and Monmouth Branch), Mr. J. G. Pearce (Birmingham Branch), Mr. L. W. Sanders (London Branch), Mr. J. Blakiston (West Riding of Yorkshire Branch).

British Foundry Medal

Mr. Barrington Hooper, C.B.E., and Industrial Newspapers, Limited, have very generously offered to provide annually a medal for presentation to the author of the best Paper presented to the Institute each year. The Council have had very much pleasure in accepting the munificent offer of Mr. Hooper and his company, and in collaboration with the donor have drawn up the following rules to govern the award:—

> The award to be known as the British Foundry Medal and to be given to the author of the Paper adjudged by the Council to be the best presented to any meeting of the Institute and accepted for publication in the Proceedings.
>
> A cash award of £10 to accompany the medal, which cash award may, at the discretion of the Council, be divided between the recipient of the medal and any other author or authors adjudged by the Council to be worthy of such award, though perhaps not entitled by merit to receive the medal.
>
> If in any year, in the opinion of the Council, no Paper is of sufficient merit, then either or both the medal and the cash award can be carried forward to the next year or cancelled for that year, at the discretion of the Council.
>
> The award, if made, to take place at the Annual Conference.

The first award will be made at the Annual Meeting, 1944, in respect of Papers to be published in the Proceedings, Volume XXXVI.

Edward Williams' Lecture

The Edward Williams' Lecture for 1942 was prepared by Dr. H. W. Gillett, of the Battelle Memorial Institute, Columbus, Ohio, whose subject was "Foundry Teamwork." The lecture was presented to the Annual Meeting on behalf of the author by Mr. J. G. Pearce, Director and Secretary of the British Cast Iron Research Association.

Branch Activities

Full syllabuses of meetings were arranged by the Birmingham, East Midlands, Lancashire, London, Middlesbrough, Scottish, Sheffield, South African, Wales and Monmouth, and West Riding of Yorkshire Branches, and by the East Anglian, Bristol, Burnley, Falkirk, and Lincoln Sections. At most meetings satisfactory attendances have been recorded and the Council desires to place on record their gratitude to the Presidents, Councils, and Secretaries, and to the authors of Papers presented at these meetings. The number of meetings held during the year represented over 80 per cent. of the normal number of meetings held in a peacetime year.

At the October meeting of the Council, an application by the Bristol Section of the Wales and Monmouth Branch to become the Bristol and West of England Branch of the Institute was accepted, and the new Branch formally commenced its activities in January, 1943, when the Council held a meeting at Bristol.

Educational Work

The following are the results of the examinations held under the auspices of the City and Guilds of London Institute and in conjunction with the Institute in April and May, 1942:—

	No. of candidates.	Pass 1st class.	Pass 2nd class.
Patternmaking— Intermediate grade	22	4	9
Patternmaking— Final	24	2	12
Foundry Practice and Science	36	7	15

Buchanan Medals and Book Prizes were awarded to:

PATTERNMAKING—*Final.*

Silver Medal.—No award.

Book Prizes.—Mr. Alex. S. H. Sawers, external candidate at Denny, Stirlingshire; Mr. John W. Hodgkinson, External candidate at Bradford.

FOUNDRY PRACTICE AND SCIENCE.

Silver Medal.—Mr. Alan Percival Scattergood, School of Art, Derby.

Book Prizes.—Mr. George D. Brockway, Technical College, Darlington; Mr. Donald S. Broadbent, Technical College, Huddersfield.

Publications

Volume XXXV of the Proceedings was published in February, 1943, and a number of Papers were circulated to members during the year. Arrangements have been made for a number of Papers to be presented to the Annual Meeting, 1943, and for others to be circulated.

Kindred Associations

The Institute maintains cordial relations with a number of kindred societies, joint meetings between local Branches of the Institute and a number of societies having been held during the year. It was with pleasure that once again the Council received an Exchange Paper to the 1942 Annual Meeting from the American Foundrymen's Association, the author being Mr. Carl F. Joseph. The 1942 Exchange Paper to the American Foundrymen's Association was prepared by Mr. C. H. Kain and Mr. L. W. Sanders. A similar exchange of Papers is being made to the Annual Meetings of the Association and the Institute in 1943.

The Institute has continued as an Affiliated Member of the Council of Ironfoundry Associations and is represented on the Executive and Finance Committee by the President. Mr. J. W. Gardom, Convener of the Technical Committee, Mr. P. A. Russell, Convener of the Cast Iron Sub-Committee, and Mr. A. E. Peace, Convener of the Malleable Cast Iron Sub-Committee, continue as representatives of the Institute on the Technical Advisory Committee of the Council.

During the year the Association of Bronze and Brass Founders has been formed and the Institute is represented on the Technical Committee of that Association by the Convener of the Non-Ferrous Sub-Committee of the Technical Committee (Mr. F. Hudson). Mr. G. T. Hyslop (member) is Vice-President of the Association and Chairman of its Technical Committee.

Ironfounding Industry Fuel Committee

At the invitation of the Ministry of Fuel and Power, the Council of Ironfoundry Associations, with the active co-operation of the British Cast Iron Research Association and the Institute, established the Ironfounding Industry Fuel Committee in October, 1942. The Committee is composed of three representatives of the British Cast Iron Research Association, with Mr. J. G. Pearce as Chairman, and three representatives of the Institute, whose Acting Secretary is Honorary Secretary of the Committee. Mr. W. J. Driscoll, B.Sc. (Eng.) (Associate Member), of the British Cast Iron Research Association, has been appointed full-time Fuel Officer. Since the formation of the Committee fourteen Regional Panels have been formed corresponding with the Regional areas of the Ministry of Fuel and Power. The Branches of the Institute have been intimately associated with the formation of these Regional Panels and in many cases the Honorary Secretaries of the Branches of the Institute of British Foundrymen have been appointed Secretaries of the Regional Panels. To those gentlemen whose commitments must already be heavy, the Council extends its thanks for these extra duties which they have so kindly agreed to carry out.

The work of this Committee is considered to be of the utmost national importance during the war and will no doubt greatly assist the industry towards more efficient operation in post-war years.

The financing of the Committee has been undertaken by the Council of Ironfoundry Associations.

Council

Four meetings of the Council and nine meetings of the Executive, and other standing Committees have been held in London, Birmingham, Bristol, and Manchester.

Of the ten members of the Council who were elected by ballot for a period of two years, five retire each year. Those who retire at the Annual Meeting to be held in London on June 26, 1943, are Mr. V. Delport, Mr. Barrington Hooper, Mr. E. Longden, and Mr. P. A. Russell. Mr. D. Sharpe, whose term of office expires in 1943, was elected Junior Vice-President in 1942, and is therefore an ex officio member of the Council for 1943-44.

The Council expresses to Mr. S. H. Russell, Past-President and Honorary Treasurer, its grateful thanks for the manner in which he has conducted the Institute's finances during the past year. The Council is also indebted to Mr. J. W. Gardom, who, as Convener of the Technical Committee, has devoted much of his time to the many aspects of the work which the Committee has done.

Officers

It is expected that at the Annual Meeting in June, the Council will nominate Mr. D. Sharpe as President for 1943/44, and Mr. D. H. Wood for re-election as Senior Vice-President. The Council has nominated Mr. J. W. Gardom as Junior Vice-President for 1943/44, and this nomination will also be placed before the Annual Meeting.

Annual General Meeting, 1942

The Annual General Meeting was held at the Waldorf Hotel, London, on Saturday, June 20, 1942. After the formal business meeting, Major R. Miles delivered his Presidential Address, which was followed by the presentation of Awards and the Edward Williams Lecture. About 130 members attended the Annual Luncheon, which was followed by two technical sessions.

The Annual General Meeting in 1943 will be arranged on very similar lines and will also be held at the Waldorf Hotel, London, on Saturday, June 26.

Staff

The Secretary continues to be engaged at the Iron and Steel Control, but is able to keep in close touch with the Institute's work.

(Signed) Richard Miles, President; John Bolton, Acting Secretary.

ELEVENTH ANNUAL REPORT OF THE TECHNICAL COMMITTEE

During the past year four meetings of the Committee and numerous meetings of the Sub-Committees have been held at Birmingham, Manchester, and in

London. Brief summaries of the work of the Sub-Committees follow.

Cast Iron Sub-Committee.—The Sub-Committee has prepared a report, entitled, "Meeting the Raw Material Supply Position," which is to be presented to the Annual Meeting in June, 1943. The purpose of the report is to assist founders to overcome difficulties associated with the scarcity of low-P, low-C cast iron.

Non-Ferrous Sub-Committee.—Following the revision of a number of British Standard Specifications to meet the need for the conservation of tin, the Sub-Committee presented a report on "Low-Tin and Tin-Free Bronzes and Brasses," to the Annual Meeting in 1942. Further work has been done during the year at the request of the Admiralty, particularly the preparation of a report on a copper-antimony-nickel gear alloy developed in Canada. This report is to be presented to the Annual Meeting, 1943.

The Sub-Committee has also collaborated with the British Non-Ferrous Research Association and the Association of Bronze and Brass Founders in the preparation of a report on "Cast Brasses A. and B. (B.S.S. 1025-1028): Substitutes for Gunmetal," which will probably be published in the near future. There is also in course of preparation an atlas of defective non-ferrous castings, which is to be presented to a number of Branches during the next session.

The Committee has been strengthened during the year by the nomination to the Sub-Committee of Mr. T. J. Peake, representing Superintendent, Technical Applications of Materials, Ministry of Supply, Mr. A. H. Waterfield, R.D.Mat., Ministry of Aircraft Production, and Mr. C. Coldron Smith, representing Engineer-in-Chief, Admiralty, and by the co-option of Mr. G. T. Hyslop. Dr. L. B. Hunt has resigned his convenership of the Sub-Committee and was succeeded by Mr. F. Hudson.

Mechanical Development Sub-Committee.—Meetings of the Sub-Committee, which was appointed in May, 1942, have been held monthly since June, 1942, and the ground work of the Sub-Committee's proposed comprehensive survey of mechanical handling methods has been almost completed. It is considered that the ultimate publication of this work will be of considerable value and particularly to students.

Costing Sub-Committee.—After some minor revisions had been made the "Recommendations for the Establishment of Costs in a Grey Iron Foundry," which the Costing Sub-Committee originally presented to the Annual Conference in 1937, was reprinted in cyclostyle form in order to satisfy the continued demand for this report.

Melting Furnaces Sub-Committee.—A number of meetings were held during the year, when the Sub-Committee prepared the section on melting furnaces for inclusion in the Technical Committee's report on fuel economy in foundries, referred to below. The report on "Melting Furnaces for Grey Cast Iron," prepared by the Sub-Committee and published to members of the Institute as Special Report No. 2, in January, 1940, was made generally available during 1942.

Malleable Cast Iron Sub-Committee.—The Sub-Committee's work on the proposed revisions to the B.S.I. 309 and 310 specifications is practically complete, but revision of the physical test requirements has been held over during the war period. In collaboration with the Sub-Committee the British Standards Institution issued amendments to the specifications in 1942, covering the clause regulating the provision of test-bars and the machinability clause.

Through the Sub-Committee the Institute was represented on a number of Sub-Committees of the Technical Advisory Panel to the Joint Directors for Iron Castings.

Sands Sub-Committee.—The Sub-Committee are working on testing procedure for oil sand, and the investigations on type of specimen and drying procedure are receiving attention at the moment. The possibility of using saw-dust or wood flour in moulds is being considered, and information on the practical application collected. The collection and classification of information on defects in castings is proceeding, and it is hoped to have information on this subject ready for publication at an early date. Mr. J. J. Sheehan had to resign his convenership of the Sub-Committee and was succeeded by Mr. A. Tipper.

Silicosis and Fuel Economy

In addition to the work of the Sub-Committees the Technical Committee has also been giving considerable attention during the past year to the question of silicosis. The position has, however, become extremely complex, and in view of the commercial aspect of many of the questions involved the Technical Committee is not proceeding further in the matter, but passing on the information which it has collected to the appropriate trade organisations.

An account of many aspects of the advisory work which was carried out during 1941-42 on behalf of the Ministry of Supply and under the direction of Mr. J. W. Gardom, has been presented to the majority of Branches of the Institute by the Convener. It is anticipated that this Paper will be published and circulated to members during the coming year.

At the suggestion of the Ministry of Fuel the Technical Committee has prepared during the last three months a comprehensive report on fuel economy in foundries. For the purpose of preparing the report a special Committee was convened, representing all aspects of the industry, iron, malleable and non-ferrous, including the light alloys. At its first meeting, in February, the Committee arranged for the preparation of a first draft of the report, which was finalised at the second meeting, held in March. The report is shortly to be issued as Special Report No. 3 to all members of the Institute, and in order that the Committee's work may be of maximum value to the fuel efficiency campaign a copy of the report is being distributed to every foundry in the country. The recommendations contained in this report have been endorsed by the Ironfounding Industry Fuel Committee and the Technical Committees of the Association of Bronze and Brass Founders and the Light Metal Founders' Association, to whom the Committee wish to express their thanks.

The Association of Bronze and Brass Founders, established during the past year, has invited the Convener of the Non-Ferrous Sub-Committee (Mr. F. Hudson) to represent the Institute on their Technical Committee.

In response to a request from the Ministry of Fuel and Power, the Council of Ironfoundry Associations, with the co-operation of the B.C.I.R.A. and the I.B.F., has formed during the past year the Ironfounding Industry Fuel Committee. Mr. Gardom, Mr. Russell, and Mr. Peace, as the Institute's representatives to the Technical Committee of the Council, serve on the Fuel Committee.

Through the Committee the Institute continues to be well represented on a large number of B.S.I. Committees.

(Signed) J. W. Gardom, Convener.

BALANCE SHEET 31st December, 1942

LIABILITIES.

	£ s. d.	£ s. d.
SUNDRY CREDITORS	580 6 7	
SUBSCRIPTIONS PAID IN ADVANCE	330 15 0	
SECRETARY'S POLICY FUND	18 8 8	
		929 10 3
THE OLIVER STUBBS MEDAL FUND:—		
Balance from last Account	223 10 2	
Interest to date	10 5 4	
	233 15 6	
Less: Cost of Token	2 7 6	
		231 8 0
THE BUCHANAN MEDAL FUND:—		
Balance from last Account	118 10 10	
Interest to date	4 9 7	
	123 0 5	
Less: Cost of Medal and Prizes	5 5 4	
		117 15 1
THE E. J. FOX MEDAL FUND:—		
Balance from last Account	510 5 11	
Interest to date	16 4 0	
	526 9 11	
Less: Cost of Token	3 10 0	
		522 19 11
TECHNICAL DEVELOPMENT FUND:—		
Balance from last Account	455 4 4	
Interest to date	12 0 8	
		467 5 0
CHARTER RESERVE FUND		400 0 0
ACCUMULATED FUND:—		
Balance from last Account	3,640 14 0	
Excess Income over Expenditure for the year ended 31st December, 1942	708 10 1	
		4,349 4 1
		£7,018 2 4

S. H. RUSSELL, *Hon. Treasurer*.
TOM MAKEMSON, *Secretary*.

Parliament Mansions, Victoria Street,
London, S.W.1
28th April, 1943.

ASSETS.

	£ s. d.	£ s. d
CASH IN HANDS OF BRANCH SECRETARIES:—		
Lancashire Branch	48 10 1	
Birmingham Branch	41 1 4	
Scottish Branch	18 4 6	
Sheffield Branch	35 9 6	
London Branch	22 0 10	
East Midlands Branch	31 12 1	
West Riding of Yorkshire Branch	20 15 10	
Wales and Monmouth Branch	4 8 10	
Middlesbrough Branch	20 18 7	
Newcastle Branch	21 18 6	
South African Branch	52 1 4	
		317
CASH AT BANK:—		
LLOYDS BANK LTD.	355 1 9	
MANCHESTER & SALFORD SAVINGS BANK	778 1 2	
POST OFFICE SAVINGS BANK	253 2 6	
		1,386 5 5
CASH IN HAND—SECRETARY'S POLICY FUND	18 8 8	
Do. —HEAD OFFICE PETTY CASH	1 2 4	
SUNDRY DEBTORS, ETC.:—		19 11 0
Subscriptions due and subsequently received	48 6 0	
Payments in advance	8 5 0	
SUPERANNUATION INSURANCE:—		56 11 0
Unexpired premium		18 8 7
THE OLIVER STUBBS MEDAL FUND:—		
£342 5s. 7d. Local Loans 3% Stock at cost	200 0 0	
Balance at Lloyds Bank Ltd.	31 8 0	
		231 8 0
THE BUCHANAN MEDAL FUND:—		
£125, 3½% Conversion Stock at cost	98 6 9	
Balance at Midland Bank, Ltd.	19 8 4	
		117 15 1
THE E. J. FOX MEDAL FUND:—		
£462 19s. 3d., 3½% Conversion Stock at cost	500 0 0	
Balance at Lloyds Bank, Ltd.	22 19 11	
		522 19 11
TECHNICAL DEVELOPMENT FUND:—		
Balance at Manchester & Salford Savings Bank		467 5
INVESTMENTS:—		
£650, 3½% War Loan at cost	630 8 4	
£653 19s. 0d., 3% Local Loans at cost	451 13 8	
£964 5s. 1d., 3% Funding Loan at cost	897 14 11	
£400, Leeds Corporation Mortgage	400 0 0	
£1,000 3% Defence Bonds	1,000 0 0	
£500, 3% Savings Bonds	500 0 0	
		3,879 16 11
FURNITURE, FITTINGS, AND FIXTURES:—		
Balance from last Account		1 0 0
		£7,018 2 4

We have prepared and audited the above Balance Sheet with the books and vouchers of the Institute and certify same to be in accordance therewith.

J. & A. W. SULLY & Co.,
Chartered Accountants, Auditors

INCOME & EXPENDITURE ACCOUNT for the Year Ended 31st December, 1942

EXPENDITURE.

1941 £ s. d.	1941 £ s. d.		£ s. d.	£ s. d.
176 16 3		POSTAGES		203 7 6
819 12 4		PRINTING AND STATIONERY including printing of "Proceedings"		896 0 6
67 12 2		COUNCIL COMMITTEE AND ANNUAL MEETING EXPENSES		154 14 3
		BRANCH EXPENSES:—		
	103 1 4	Lancashire................	116 15 1	
	59 11 3	Birmingham	71 8 8	
	76 11 2	Scottish	82 5 6	
	13 6 6	Sheffield	21 10 6	
	62 15 5	London	69 9 1	
	49 15 7	East Midlands	48 11 11	
	3 10 0	Newcastle	7 5 6	
	48 12 3	West Riding of Yorkshire ..	41 4 2	
	17 15 6	Wales and Monmouth	47 5 2	
	26 15 0	Middlesbrough	23 11 5	
	50 3 3	South African	— —	
511 7 3				529 7 0
12 12 0		AUDIT AND ACCOUNTANCY CHARGES		15 15 0
84 10 5		INCIDENTAL EXPENSES........		167 1 3
		SUBSCRIPTIONS:—		
	10 10 0	British Standards Institution	10 10 0	
		Council of Ironfoundry Associations	26 5 0	
	5 5 0	Joint Committee on Materials and their testing..........	1 1 0	
15 15 0				37 16 0
586 4 2		SALARIES: — Secretary and Staff *less* Received		638 11 8
55 5 10		SUPERANNUATION INSURANCE (Secretary)		55 5 10
110 1 0		RENT, RATES, &c., of Office *less* Received		106 8 0
44 2 11		FURNITURE AND FITTINGS— Amount written off		— —
21 19 5		AIR RAID PRECAUTIONS AND FIRE WATCHING		16 14 4
17 7 0		WAR DAMAGE INSURANCE		6 5 0
2,523 5 9				2,827 6 4
864 12 3		EXCESS OF INCOME OVER EXPENDITURE CARRIED TO BALANCE SHEET		708 10 1
8,387 18 0				£3,535 16 5

INCOME

	£ s. d.	£ s. d.	1941 £ s. d.	1941 £ s. d.
SUBSCRIPTIONS RECEIVED:—				
Lancashire Branch............		510 0 0		472 10 0
Birmingham Branch		578 15 0		529 19 0
Scottish Branch		404 14 6		388 10 0
Sheffield Branch		274 1 0		257 15 6
London Branch		608 10 0		521 17 0
East Midlands Branch		311 6 0		305 0 0
Newcastle Branch		91 6 6		104 3 6
West Riding of Yorkshire Branch		213 13 6		229 19 0
Wales & Monmouth Branch....		251 8 0		147 18 6
Middlesbrough Branch		129 10 6		101 5 6
South African Branch		102 1 4		201 1 6
Unattached Members		46 1 0		43 13 0
		3,521 7 4		3,303 12 6
Add:—				
SUBSCRIPTIONS IN ADVANCE 1941	166 7 6		111 5 0	
SUBSCRIPTIONS DUE 1942	48 6 0	214 13 6	65 13 6	176 18 6
		3,736 0 10		3,480 11 0
Less:—				
SUBSCRIPTIONS IN ADVANCE 1942	330 15 0		166 7 6	
SUBSCRIPTIONS DUE 1941	65 13 6	396 8 6	75 15 0	242 2 6
		3,339 12 4		3,238 8 6
SALE OF PUBLICATIONS..........		57 7 0		27 2 0
INTEREST ON INVESTMENTS AND DEPOSITS		134 17 2		97 14 6
JOHN SURTEES MEMORIAL EXAMINATION SURPLUS		3 19 11		24 13 0
		£3,535 16 5		£3,387 18 0

PRESIDENTIAL ADDRESS

BY DANIEL SHARPE

MAJOR MILES AND GENTLEMEN,

I have chosen for the subject of my Presidential Address:—

"*Teach a man how to ask questions and you have given him the key to knowledge.*"

The foundry industry is a combination of science and art and the analytical mind which formulates questions goes a long way to answering them. It would be difficult to find a trade more prone to developing conundrums than the foundry industry. The lack of precision in moulding, melting and pouring castings calls for an individual deductance, often on the spur of the moment, which is found in few other lines of production. Decisions have to be made to meet the ever recurring emergencies, which if not acted on at once may mean scrapping valuable work.

During a man's normal lifetime in such a varied trade as metal founding, many changes in both theory and practice take place. Most of the changes are based on very small modifications which, when seen over a period of years, produce the appearance of major changes. Our present practice in even the most advanced foundries, has much in common with the old craft days, when a great deal of the work was done by individuals who had little opportunity of comparing their practice with that carried on in other similarly employed shops.

Thanks to the Institute of British Foundrymen, we have to a considerable extent changed this condition by providing lectures, discussions, works visits and association with a technical Press, which have done much to widen the experience of managers and workers alike. The education facilities offered to the young foundryman in all the varied branches of the trade have also been advanced, and we are hoping that even greater strides will be possible in the near future, thus inducing a good grade of youth to take up the foundry as a means of making a satisfactory living and an interesting career. The structure of the present foundry practice has a solid foundation on the records of the past, while the practice of the future is dependent on the performance of the present generation, that means you and me. We must treat this trust with great care if we are to produce a lasting prosperity for the generations to follow us.

Although we must take heed of the craftsmanship of yesterday, and to-day, it would be disastrous if the oft-championed claim for preserving the craft allowed us to ignore the greater claim of modern methods, which have done so much to improve the speed and economy of production, besides providing greatly improved working conditions both in comfort and safety, as compared with half a century ago. In dealing with this problem we must be both reticent and venturesome.

Changing Designs and Requirements

The foundry industry is under the great handicap, in the bulk of its manufactures, in not being the producer of a finished article. Most castings are designed and specified by some other branch of engineering, so that the finished product of the foundry becomes the raw material of the later process. Here is an opening for education outwith our own industry. We must give credit to many engineering firms for taking advantage of such knowledge as we pass on to them for modifying their designs to enable us to produce satisfactory castings.

The ever increasing up-grade in specifications, necessitated by changed requirements in strength, lightness, rigidity and exact dimensions, has made the foundry industry tighten up on all these factors. We are to-day asked to supply castings to tolerance of only a few thousands of an inch in dimensions, and to mechanical and chemical limits which call for metallurgical practice of a high standard. In dealing with these increased demands, the more advanced foundrymen have kept fully up with specifications, and it will not be long before many of the hit-and-miss methods of the past will be analysed by intelligent investigators when the rich experience of the old generation will form the basis of a general structure for substantial improvement.

In all these changes the symbol of our Institute is indicated "Science Hand in Hand with Labour." So long as we can advance together with science pointing the way to labour, we have much benefit to derive from the combination. If we can improve the quality of our output and at the same time sell at prices attractive to our customers, we should do something to make the life of the man-power in our foundries more attractive. I have been in foundries at home and abroad where working conditions were orderly, clean and labour-saving. I have been in other foundries, also at home and abroad, where conditions were repulsive in every detail. We must put the latter type out of action either by regulation or competition, as it is good for neither employer nor employee to live and work in such miserable conditions.

The first essential to improved working conditions is profitable trading, and much good will come of any scheme arranged to remove the pre-war attitude of some buyers of castings who squeeze founders to accept work at non-remunerative prices. Foundrymen who play into the hands of such buyers are doing a great disservice to the industry to which they belong.

Future in Specialisation

The future holds out great opportunities for specialisation where methods peculiarly suitable to the production of a distinct grade of casting can be introduced to reduce the cost of manufacture, and improve quality and accuracy, and I foresee steadily increasing efforts to travel along the specialist line. The mere introduction of mechanical plant into a foundry will not produce economic results, but the introduction of mechanical plant intelligently designed, laid out and controlled by highly skilled men, will work wonders in economy of labour, time and money.

The man behind the machine is much more valuable than the machine and it is the finding and training of such men that is our most important problem. If we can remove much of the drudgery from the skilled operative by the introduction of mechanical appliances, we can hope for a bigger flow of good labour into our shops. Much valuable time of a highly skilled moulder is employed doing work which raw labour could undertake successfully with mechanical plant under skilled supervision. I know of no trade offering better chances of improvement to an intelligent man than the foundry offers to-day. Such a man would want a wide education covering patternmaking, moulding, fettling, machinery maintenance and above all be production minded. Add metallurgical training and you have rounded off the major qualifications. "Are we producing many men of this type in British foundries to-day?" should be a pertinent question before the Education Committee of this Institute.

The ever increasing mechanical aid has brought many engineers into the management of foundries, and, like it or not, I am afraid we must admit that this type of foundry manager is increasing because he has had a wider training than a man graduating from a patternmaking or moulding apprenticeship. I have observed many changes in practice during a period of 40 years and mention of some of the more important changes may be useful.

Thanks to the patient work of a number of men, we have developed quite a new technique in sand preparation. The international drive to find new and more consistent sand conditions has given us synthetic sands which at first hand may appear expensive, but when costed in relation to flowability, moulding speed, skin finish and reduced fettling often prove to be extremely economic. Mention should be made of the greatly improved sand mills, aerators and distributing conveyors. Mould facings have also been overhauled and we now have the call on many standard facings suitable to a wide variety of metals. Oil sand cores which were being developed by the steelfoundries about 35 years ago when such ingredients as molasses and sour beer were used have developed into one of the bright flowers in the foundry trade. Green-sand castings are now made where dry sand or loam was used when I was a youth.

Progress in Mechanisation

The introduction of power moulding has almost all been developed during my lifetime, and as I have been privileged to be in the forefront of the movement I may be permitted to say that we are still on the fringe of this development. Given a production demand justifying speeding up of patterns and machines, I am sure the moulding and core-making machine manufacturer will easily master the job.

Handling of materials in a foundry is a large part of the day's work and where intelligently applied and maintained the use of sand, mould and metal conveyors can reduce confusion, drudgery, fatigue and costs. Cleaning and fettling of castings has been greatly helped by modern methods. Metallurgical control of metal mixing, melting, annealing, heat-treatment and tempering are in the hands of intelligent advocates, and the improvement in quality justifies our confidence that when better metals are asked for, our metallurgists and melters will be ready to supply them. The accurate costing of each operation in a foundry, together with detailed data of production, has done much to unify selling prices and deserves all the attention that it is receiving.

The intensive conditions of production due to abnormal war demands will require to be carefully watched when the changeover to commercial life returns. Many factories are to-day working on types of casting which will not be required in peacetime and much forethought is being given to the change back to normal work. This should be a chance for the Institute of British Foundrymen to take a hand in straightening out many of the difficulties which are certain to develop and I feel sure that the services of our able Technical Committee will be of great value in helping members in peacetime as they have done in war.

I would like to pay a tribute to the capable way in which the equipment builders and material suppliers have helped in the gigantic developments occasioned by the increased demand for more and better castings. They have given the foundryman the tools and the foundryman has manfully done the job. We are not through with the war yet, but the efforts of all personnel of the foundry industry deserve well of the country for the way they have done their duty.

Vote of Thanks to President

MR. V. C. FAULKNER, proposing a vote of thanks to the President, said the address was a clarion call for action, and he was convinced that under the President's erudite and distinguished leadership all the various committees would work with added vigour knowing that they had his entire whole-hearted co-operation. His mind went back to the day during the last war when the President and he first met in Leven: the President as director of the steelfoundry and he as the metallurgist, putting into operation the electric furnaces which were being worked for the good of another war. This time they were all working in a much larger sphere for the prosecution of a still greater and bloodier war.

MR. J. G. PEARCE, who seconded the vote of thanks, said he could endorse the text of the presidential address, because on the technical and scientific side it was always felt that if it were possible to pose an accurate question, they were half-way towards finding the answer. The more difficult problem was often to ask the question in the first place. The Institute was to be very warmly congratulated on having elected Mr. Sharpe to the presidency, for he had a unique combination of experience both in the manufacture of castings and in the design and manufacture of equipment for their production. At this juncture in the history of the craft that would be very beneficial both to the Institute and to the industry.

The vote of thanks was heartily given.

PAPERS PRESENTED TO THE ANNUAL GENERAL MEETING, LONDON

Sixth Edward Williams' Lecture

Paper No. 766

The Contribution of the Steelfounder to Marine Engineering

By STANLEY FABES DOREY, D.Sc., Wh.Ex.*

Historical

The art of steelmaking, as we understand the term, goes back roughly two centuries. The first to develop a process of steelmaking by fusion was Benjamin Huntsman, a Doncaster clockmaker, who in 1740 established works in Sheffield for the manufacture of crucible steel, and it is, therefore, safe to assume that the earliest examples of the steelfounder's art were made of crucible steel. Many early examples of crucible steel castings were to be found in the Sheffield district at the beginning of last century; the wearing parts of the old wooden hammers were made of this material. Crucible steel was first made in the U.S.A. in 1831, and by Krupp in Germany in 1832.

It is probable that Jacob Meyer, of the firm of Meyer & Kuhne, Bochum (later Bochumer Verein), was the first to mould from wooden patterns, although this claim is disputed by Krupps. In 1851 Meyer & Kuhne cast a bell, weighing approximately 2½ tons, which was on view at an exhibition held in Düsseldorf in the same year, and in 1855 at the Paris Exhibition they showed two further bells of still greater weight and two slabs each weighing some 7½ tons, all of crucible steel. Other countries took up the challenge, notably France and the United States of America. In the latter country the first steel castings were made by the William Butcher Steel Works in the late 60's, and A. W. Hainsworth, of Pittsburgh, was producing crucible steel in 1870. In France, A. Pourcel, of the Terre-Noire Company, did much to improve the quality of steel by recognising the part played by silicon and manganese. The advent of the Bessemer process (1855) marked a great forward step in steelmaking, and steady progress was made in the production of steel castings, a still further impetus being provided by the introduction of the Siemens process (1867).

Early reference to the manufacture of steel castings are to be found in Papers presented to the Iron and Steel Institute in 1883 by W. Parker, a distinguished predecessor of the author, who at that time was chief engineer surveyor to Lloyd's Register, also by W. D. Allen, who was connected with the firm of Henry Bessemer & Company, Sheffield. The latter claimed to have produced castings from Bessemer steel for many purposes, "from an intermediate shaft to a corkscrew or a table knife," and in all these applications he had found Bessemer steel to be well adapted to the purpose. Parker stated that in the previous year (1882) several applications had been made by various firms to the Committee of Lloyd's Register of Shipping for the approval of the use of steel castings for such purposes as stems, sternframes, rudders, tiller quadrants, and other parts of vessels, and also for crankshafts, levers, link blocks and other parts of marine engines, these parts having previously been made of wrought iron.

In particular, Parker referred to three steelmakers who had been very successful in the manufacture of castings, namely, Jessop & Sons, of Sheffield; Spencer & Sons, of Newcastle-upon-Tyne; and the Steel Company of Scotland, Limited, Glasgow. His Paper contained numerous illustrations of the above-mentioned companies' productions, including crankshafts, sternframes, rudder frames, stem pieces, anchors, dredger buckets, etc. Some of these castings were made of crucible steel and others of Siemens-Martin acid open-hearth steel. In the discussion on Parker's Paper it was stated that a sternframe and rudder were made in steel in April, 1881, by Jessop, and up to 1883 "some 20 cast-steel crankshafts were at work in steamers running across the Atlantic and employed in other trades, and there was not the slightest defect in any one of them." Parker also stated that 17 cast-steel sternframes had been made by various makers, the largest of these being 6½ tons in weight, and that he was not aware that any of these had proved defective.

Admiralty Investigations

The interest of the British Admiralty to the use of steel castings was shown by the setting up of a Committee of Investigation, in 1883, to "ascertain what success had been obtained in producing steel castings for use in lieu of iron forgings and to consider what articles or parts of a ship and her fittings, now made of forged iron or brass castings, could be advantageously made of cast steel, especially with regard to the durability of steel castings so employed."

TABLE 1.

Firm.	Type of steel.	Size of casting.
Wm. Jessop & Sons, Sheffield	Acid open hearth and crucible	Large and small.
Vickers, Sheffield ...	Acid open hearth ...	Mainly large.
Steel Co. of Scotland	Acid open hearth ...	Mainly large.
Spencer & Sons, Newcastle-on-Tyne	Acid open hearth and crucible	Large and small.
Hadfields Steel Foundry Co. Sheffield	Converter	Small.
John Brown & Co., Atlas Works, Sheffield	Acid open hearth and crucible	Mainly large.
The Bolton Iron & Steel Works	Acid open hearth ...	Medium.
Chas. Cammell & Co., Cyclops Works, Sheffield	Acid open hearth and crucible	Mainly large.
The Stanners Close Steel Works, Wolsingham	Steel made by Atwoods Process	Large and small.

At this time several firms in this country were endeavouring to produce steel castings for marine purposes. The Admiralty Committee visited ten of them and carried out a lengthy series of crucial tests, and ultimately recommended a list of such articles or parts of a ship and her fittings which could, in their opinion, be made advantageously of cast steel, together with the routine tests proposed to be applied to each.

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* Chief Engineer Surveyor to Lloyd's Register of Shipping.

In the light of later developments, it is of special interest to note the general position in regard to the production of steel castings for ships in the years 1880-85, as given in the following table.

These firms comprised those considered best fitted for the manufacture of marine steel castings at that period. In comparison it may be stated that over 50 British steelworks are now included in the list of steel manufacturers approved in respect of steel castings by the Committee of Lloyd's Register of Shipping. In addition some 170 steelfoundries in countries other than Great Britain are included in the approved list. This is sufficient indication of the very great increase in the use of steel castings in shipbuilding and marine engineering during the past 60 years.

Obviously, therefore, the contribution of the steelfounder to marine engineering has been a big one. The work of those early pioneering firms, in the absence of analytical control as we know it to-day, formed a wonderful example of faith, hope and patience in the new-born industry.

Crucible Steel Originally Favoured

The increasing employment of steel castings in marine engineering was the natural result of the progress made in the steel foundry itself. Up to the close of the last century, despite the inventions of Bessemer and Siemens, crucible steel continued to be used for certain castings. The aforementioned Admiralty Committee expressed a definite preference for crucible steel for small castings, but added that for large articles, good, sound reliable castings could, with proper care, be produced from open-hearth steel, or from steel of special manufacture (presumably Bessemer).

Curiously enough, neither Bessemer nor Siemens had achieved much success until each collaborated with someone who could apply metallurgical knowledge to the mechanical processes which they had each developed independently. Bessemer's process needed the inclusion of manganese in the charge, and the credit for this is usually given to Robert Mushet, a Sheffield metallurgist, who obtained a patent based on the use of manganese in 1856. From this time, the success of the Bessemer process was assured. Similarly it was not until Dr. C. W. Siemens collaborated with Emile and Pierre Martin in 1864 that the successful Siemens-Martin process was evolved.

Of the many modifications of the Bessemer process, the best known and most extensively used, as far as steel castings are concerned, is the method of surface blowing developed by Robert at the Stenay Works, Meuse, in France, and later by Alexandre Tropenas of Paris. It is of interest to note that though Tropenas, who at one time was a draughtsman in the employ of Robert, developed his converter in France, his experimental work was guided both technically and financially by the Sheffield firm of Messrs. Edgar, Allen & Company, Limited.

Another converter process based on the Bessemer or pneumatic system was that developed by Mr. W. Stock, of Darlington Forge, who in 1908 patented a process in which the charge of scrap and pig-iron is melted by means of oil fuel introduced through the tuyeres. The process has been found specially suitable for producing small castings of intricate design and of light section, and has the advantage over the ordinary Bessemer process in that there is practically no absorption of impurities from the fuel.

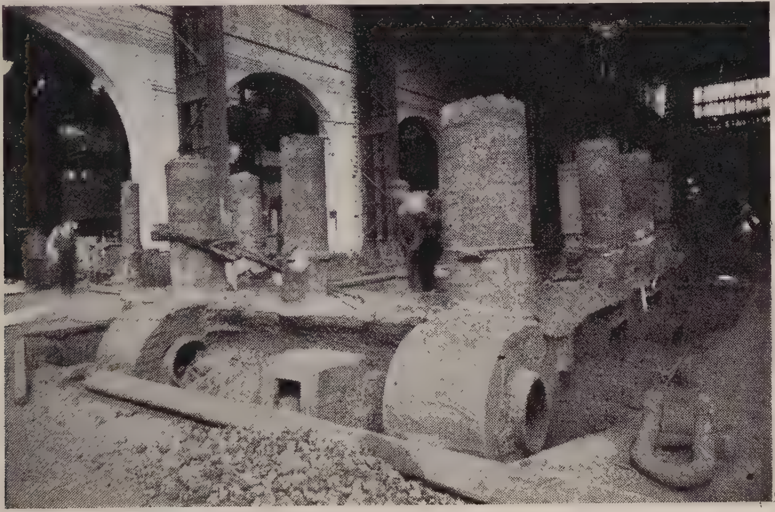

FIG. 1.—MAIN PIECE OF STERNFRAME BEING STRIPPED READY FOR ANNEALING

Continental steel founders were first in the employment of electric furnaces. No doubt the high cost of electricity in this country hindered its development in the British steel industry, where production of steel castings by means of this process commenced in the year 1910. Several types of electric furnaces have been developed since that time, the mechanical and electrical details having been considerably improved by British engineers.

In considering the influence of the steelfoundry on marine engineering, it is necessary to bear these landmarks in mind, for the major developments which have been made in foundry practice form the fundamental basis on which all progress in the use of steel castings depends.

Only in recent years has there been any organised co-operative research in the steel foundry industry, yet, possibly due to the initiative of individual firms, the progress made in the manufacture of steel castings has been remarkable. Castings are produced to-day in practically all the steels known in industry. This is a great achievement, of tremendous value in engineering, which demands such a wide range of physical properties.

Some Examples of Marine Castings

Let us at this stage review briefly those parts of a ship and her machinery which are commonly made from steel castings.

In a ship, the stem, the sternframe, propeller shaft brackets and rudder frame come first to mind. These are vital parts of a ship's structure, subjected to considerable loads arising from vibration and bending forces when in service. In the case of large ships, these parts may be built up from individual castings of considerable weight, some well over 100 tons in the cast condition, and a modern steelfoundry must be equipped with the means for handling such heavy components.

As examples, photographs of some of the castings for the s.s. "Queen Mary" are shown in Figs. 1 to 4.

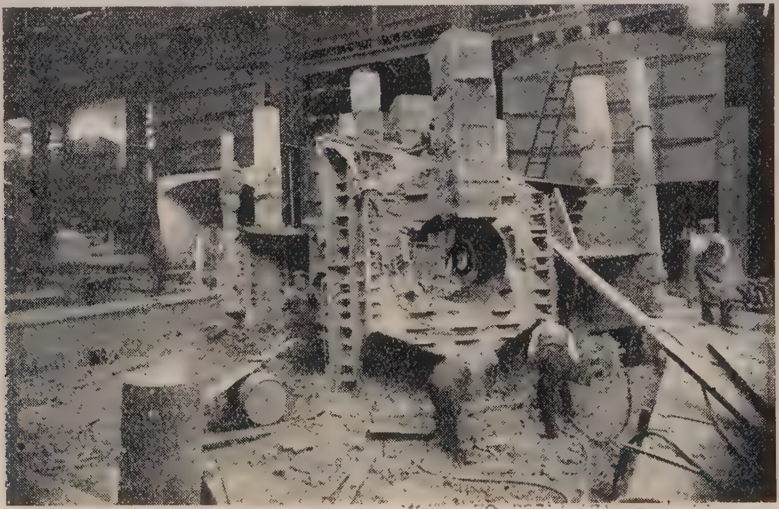

FIG. 2.—STRIPPING TRUNKPIECE OF STERNFRAME.

Fig. 1, the main piece of sternframe in process of stripping. This casting weighed 110 tons.

Fig. 2, the trunk piece of sternframe being stripped, a casting of 90 tons weight, and a core diameter of 50 in.

Fig. 3 shows the completed sternframe assembled and laid out in the machine shop. This huge cast-steel structure formed a composite casting of total weight nearly 200 tons.

In addition to the foregoing, the cast-steel stern components also included propeller shaft brackets. Each inner shaft bracket weighed 60 tons, and the two outer shaft brackets, shown in Fig. 4, comprised a total finished weight of 180 tons.

These examples, together with corresponding parts for the "Queen Elizabeth," represent the largest marine steel castings ever made (probably the largest that ever will be made); nevertheless, it must not be thought that heavy steel castings are entirely a modern development. For instance, the cast-steel sternframe for the old White Star liner "Oceanic," built as long ago as 1899, and wrecked during the last war, was made, as in the case of the "Queen Mary," by the Darlington Forge Company, and had a finished weight of 76 tons.

Examples of heavy steel castings made on the Continent are shown in Figs. 5 and 6. Fig. 5 shows the inboard propeller shaft brackets for the French liner "Normandie." Each bracket weighs 57 tons, giving a total weight for the inboard brackets alone of 114 tons.

Fig. 6 shows the cast-steel rudder for the same ship, a casting of 125 tons weight.

These two illustrations are of special interest, showing that facilities exist, or did exist, on the Continent for the production of such large and heavy castings. These castings were made at the Skoda Works in Czecho-Slovakia, and similar castings for the crack German liners "Bremen" and "Europa" were also made at these works. In this country, it is satisfactory to know that just as large and intricate steel castings can be produced in British foundries.

Apart from these main structural components, many other items of a ship's equipment are now made in cast steel. These include such important details as anchors and chain cables—the latter being a good example of ingenuity in the founder's art. In recent years, however, the cast-steel anchor cable has had to give pride of place to the resistance welded steel cable, though a number of foundries still produce them, chiefly in America. Other items are, windlass cable lifters and hawse pipes, both of which have to withstand very heavy duty, steering gear quadrants and tillers, on which the safety of the entire ship depends, watertight doors and frames, mast caps, derrick mountings and numerous other details for which strength and toughness are essential qualities.

In the present war, in which enemy strategy has been so largely directed towards the destruction of Allied shipping, cast steel has been called upon to give even greater service in the construction of parts and fittings which have to withstand the shock of underwater explosions. Valves and fittings which are directly connected to the ship's hull, stern tubes, the bedplates and framework of deck machinery, bulkhead fittings, etc., have all been found extremely vulnerable to explosive shocks when made in cast iron. In most cases, cast steel and welded mild steel have provided the solution, the choice between the two being mainly a matter of economics.

Tests for Marine Steel Castings

With this in mind, it is interesting to recall that it was primarily in regard to its resistance to shock that most doubts were expressed when cast steel was first put forward for the approval of the authorities about 1880. The Chief Surveyors of Lloyd's Register of Shipping at that time were instructed by the Society to look into the whole question of suitable tests to prove the soundness and consistency of this new material. They were not without some experience of the use of cast steel in service. Stems and sternframes, and even crankshafts for reciprocating engines, were already fitted in a few ships running in the North Atlantic, and giving satisfactory service. These had been accepted by Lloyd's Register of Shipping on a tentative basis. In this connection it is sometimes forgotten that a Classification Society bears a special responsibility in its acceptance of new methods of construction and new materials, and far from acting as a bar to progress, the Society are able to apply a judicious brake which ensures a careful and rational development based on a study of the results of tests and experience in all parts of the world. Thus it has always been the practice of Lloyd's Register of Shipping, and never more so than it is to-day, to give tentative approval to new processes and new ideas and to encourage their development as experience is acquired.

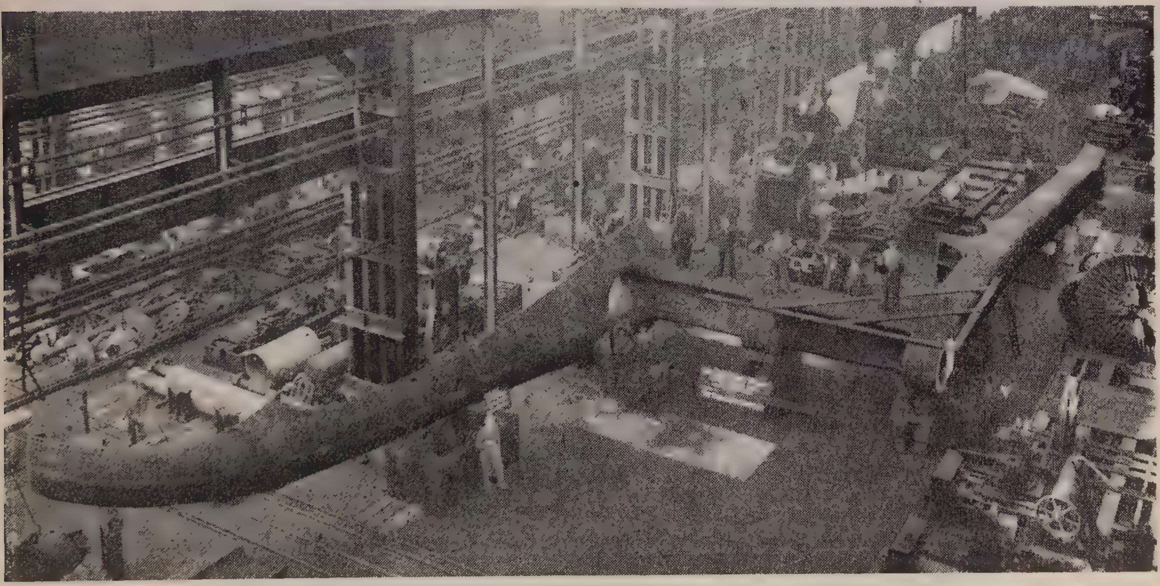

FIG. 3.—COMPLETE STERNFRAME OF NEARLY 200 TONS.

In regard to these early uses of cast steel, there had, of course, been some failures. Cracks occurred which threw suspicion on the shock-resisting property of the material, and in 1882, as the result of their investigations, Mr. Benjamin Martell and Mr. William Parker, the Chief Ship and Engineer Surveyors to Lloyd's Register of Shipping, recommended a percussive test for cast steel stems, sternframes and rudder frames. The test was to take the form of dropping the article on to hard ground, thereafter it was to be carefully examined and pounded with a hammer.

In 1885 an Admiralty Committee investigating the use of cast steel for marine purposes, and taking into account the experience already gained in the Merchant Service, recommended the adoption of acceptance tests for this material similar to those required by Lloyd's Register of Shipping. These tests included a percussive, or drop, test which is still used to-day for cast-steel sternframes, rudders, steering quadrants, crossheads and tillers, and anchors, in addition to the usual tests for tensile strength and ductility. At the discretion of the Surveyors, however, the percussive test may be omitted in the case of castings of complex design, additional tensile and bend tests being substituted.

It is fair to say, in the light of present knowledge, that early failures of steel castings were more likely due to faulty design and incorrect foundry practice, and heat-treatment, than to any inherent defect in the quality of the cast steel. Parker instanced a case of a cast-steel multi-collar thrust shaft in which fractures developed at the junction between the thin section collars and the heavy body of the shaft. It was claimed that had the shaft been cast as a solid mass, and the collars subsequently machined out of the body, the fractures would not have occurred. The problem of the junction between thin and heavy sections, and the correct positioning of feeding heads, still gives rise to considerable anxiety in the foundry even to-day.

Engineering Applications

Turning now to the use of cast steel for essentially engineering purposes, a very wide field of application at once becomes apparent. Once the superiority of mild steel over iron had been established it was a natural development to substitute cast steel for cast iron, and also, in many cases, for wrought-iron forgings. Enthusiasts in those early days visualised the total extinction of forgings both in iron and steel, and there were many arguments regarding the relative merits of forged mild steel and cast steel. There can be little doubt to-day that, with modern foundry equipment and heat-treatment, it would be difficult to decide which was the superior material for many particular purposes. In this connection, one of the latest developments is the manufacture of cast-steel gear wheels for ship propulsion, in which the helical teeth are cut direct in the periphery of the steel casting, thus dispensing with the more usual forged-steel rim.

The introduction of mild steel for boiler construction led to a rapid increase in working steam pressures and temperatures. Whereas in 1875 the common steam pressure in boilers was 60-65 lbs. per sq. in., within ten years many boilers were made to work at 150 lbs. per sq. in., and with further improvements in workmanship pressures of 180 lbs. per sq. in. rapidly came into use.

For such pressures and saturated steam temperatures, which would nowadays be considered very moderate, ordinary cast iron was quite suitable for valve chests and fittings mounted on the boiler. With the introduction of superheated steam, however, a number of failures of cast-iron fittings focussed attention on the question of the use of this material for higher temperatures. Research work was carried out, notably by H. F. Rugan and Sir Harold Carpenter, who in 1909 put forward the results of their investigations into the effects of temperature on cast iron, in a Paper read before the Iron and Steel Institute. As the result of these and other investigations it was generally agreed amongst manufacturers, users and inspecting authorities, that the use of cast iron should be restricted to saturated steam temperatures in the neighbourhood of 400 deg. F. In 1920 Lloyd's Register of Shipping regularised what had by then become general practice by prohibiting the use of cast iron for steam temperatures above 425 deg. F., and stipulated that cast steel, or other approved material, was to be used for temperatures higher than that figure in vessels classed with the Society.

Here then was a valuable contribution from the steelfounders to engineering progress. The entire development of higher steam temperatures, and the boilers and machinery associated therewith, depended upon the production of a suitable material which would exhibit sufficient strength under the combined effect of stress and high temperature. It is beyond question that without cast steel such engineering progress would have been retarded. To-day there are special types of forced circulation boilers working at steam pressures not of 180 lbs. per sq. in., but at ten times that figure, whilst superheat temperatures approach 1,000 deg. F. These thermal conditions call for special creep resisting steel for tubes, headers, pipes, valves, and other fittings, and it is satisfactory to note that the steelfounder can produce suitable castings in whatever material may be required.

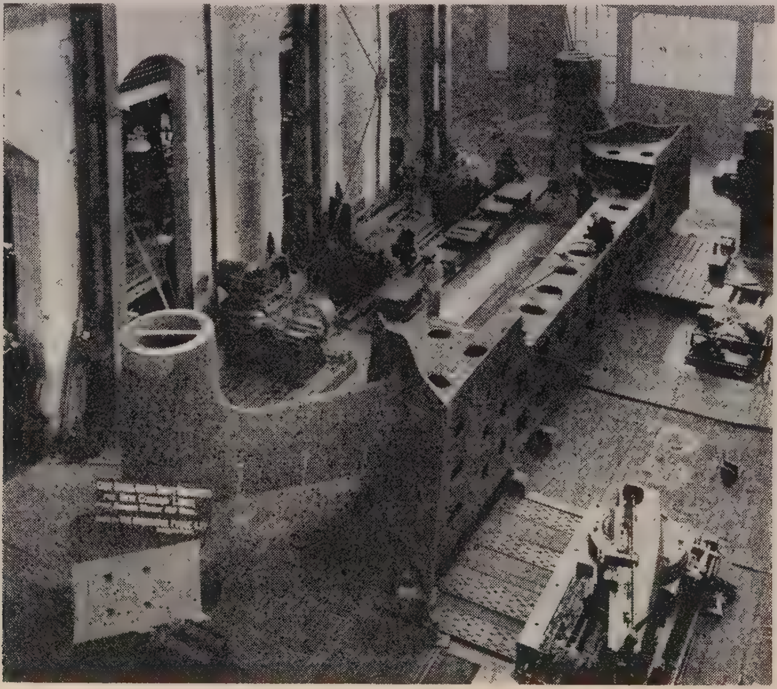

FIG. 4.—CAST STEEL OUTER SHAFT BRACKET.

Ship's Machinery

In regard to ship machinery, mention has already been made of gear wheels. In addition, besides a number of important auxiliaries, there is the main propelling machinery which may consist of steam turbines, oil engines, steam reciprocating engines, or some special combination such as reciprocating-turbo, turbo-electric or diesel-electric. In each installation cast steel in some form or other may play a prominent part.

Turbine cylinders in which high pressure steam is used are invariably made of cast steel. Some of these are very intricate castings calling for a high standard of moulding skill. For naval vessels, in which weight must be kept to a minimum, the required scantlings and consequent distribution of metal in the casting present special problems to the steelfounder. Fig. 7 represents a "close-up" view looking on the joint face of the bottom half of a turbine cylinder. The narrow cored passages in way of the gland, and bearing spaces, can be clearly seen. The turbine nozzle box, which directs the inflowing steam to the moving blades, is another intricate casting calling for a high degree of skill in core making. A nozzle box is shown in Fig. 8. An arc-shaped nozzle plate holding the stationary nozzles will be secured to the face of the nozzle box. Turbine nozzle castings, sometimes called diaphragms, are also shown in Fig. 9. In these cases the nozzle passages may be very small, and their varying dimensions must be accurate. These diaphragms are sometimes made by " casting in " the steel plates which form the nozzle passages.

Wherever severe conditions of high temperature, corrosion, abrasion or shock are encountered—and such conditions are quite common in marine engineering—then the engineer looks to the steelfounder for his material. It is not necessary to give a comprehensive catalogue of machinery parts for which cast steel has been found most suitable, but the more important items include turbine cylinders, valves and fittings, gear cases, gear wheels, Diesel engine crankshafts, connecting rods, main bearing housings and keeps, valves and valve levers, cylinder covers and liners, pistons, steam engine piston and slide valves, bedplates and engine entablatures. Figs. 10 and 11 illustrate examples of cast-steel Diesel engine crankwebs, the former weighing 6½ tons as cast, and the latter, which also embodies a balance weight, having a cast weight of 10 tons 14 cwts. Incidentally, it is of interest to note that this weight is reduced to 4 tons 6 cwts. after machining—a reduction in weight of 60 per cent.

In electrical generating machinery, baseplates, stator frames, and armature rotors are sometimes made of cast steel, and, when necessary, castings can be produced in steel having special magnetic properties. Armature rotors may form an intricate casting, as will be observed in Fig. 12.

From time to time proposals to use cast-steel crankshafts and propeller shafting for merchant ships have been accepted by Lloyd's Register of Shipping. These proposals have usually been the result of some difficulty or delay in the delivery of steel forgings, which are, of course, more commonly used for these parts. In every instance, however, the castings have been required to comply with a standard of strength equal to forged steel, and except in a few cases where casting defects have been present, they have given satisfactory service.

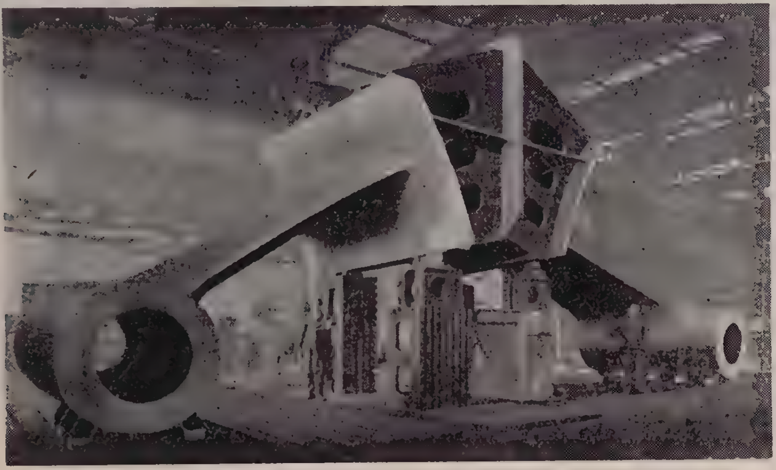

FIG. 5.—INBOARD PROPELLER SHAFT BRACKETS.

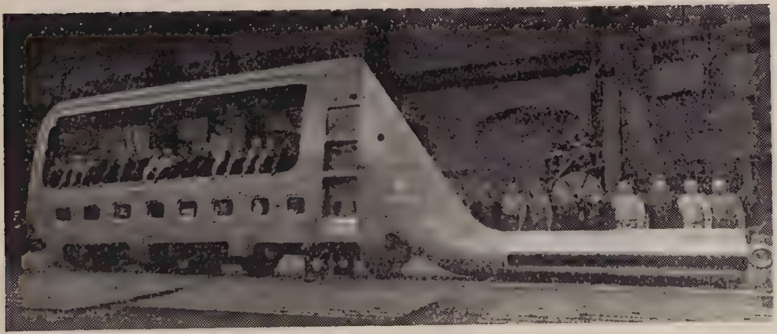

FIG. 6.—CAST STEEL RUDDER.

Chilling Bars Prohibited by Lloyds

Some years ago, I took part in an inquiry into the failure of some Diesel engine crankshaft webs made in cast steel. A peculiarity of this trouble was that fine star cracks developed in the periphery of the webs after they had been shrunk on to the pins and body pieces; further, the cracks were found only after a lapse of some time—they did not occur immediately. The inquiry opened up a complete investigation of the method of casting the webs. These had been cast vertically, and the feeding heads had been removed by flame cutting. As the position of the cracks coincided with the position of the feeding heads, it was considered that during flame cutting, molten metal had filled the cracks and obliterated them, so that, in fact, the cracks had been there, just below the surface, all the time. It was also found that some manufacturers introduced chilling bars into their castings with the object of hastening the process of freezing, and so rendering the provision of ample feeding heads less imperative. These internal chilling bars in no way prevented the formation of defects, but simply transferred them to a point midway between the chilling bar and the surface of the casting. Further, any trace of rust on the bars would result in the evolution of gases, with the consequent formation of blow-holes. It was, therefore, decided to prohibit the use of chilling bars for steel castings intended for ships classed by Lloyd's Register of Shipping.

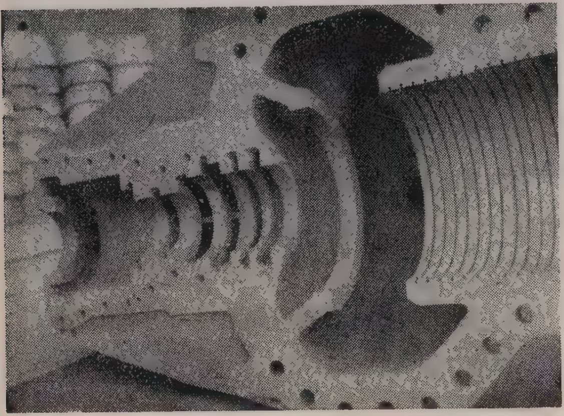

FIG. 7.—BOTTOM HALF OF TURBINE CYLINDER.

In the case of a manufacturer who cast his crankwebs in a vertical position, subsequent experiment proved that best results were obtained when the webs were cast flat and slightly inclined, with three shrinkage heads, two of which were situated at positions which would afterwards be removed completely by boring out, thus any unsound metal would be removed. Figs. 13, 14 and 15 illustrate the method used, Fig. 13 showing the crankweb as cast, Fig. 14 after removal of the shrink heads, and Fig. 15 after boring. Fig. 16 shows a section through such a crank web and reveals a good clean casting. The well-rounded edges should be noted. These facilitate casting and obviate sand flaws.

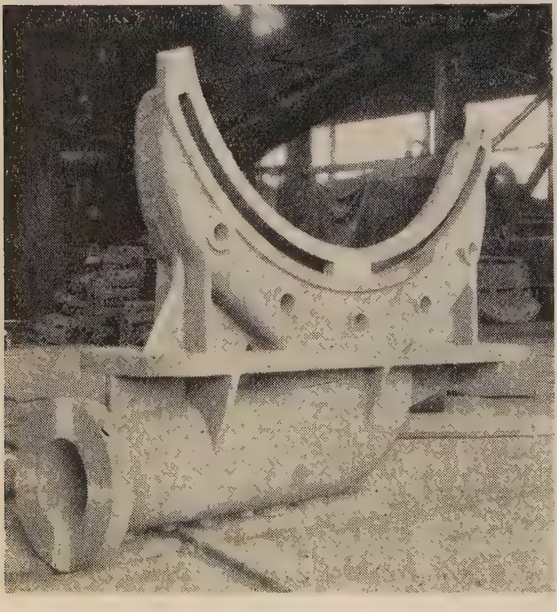

FIG. 8.—NOZZLE BOX.

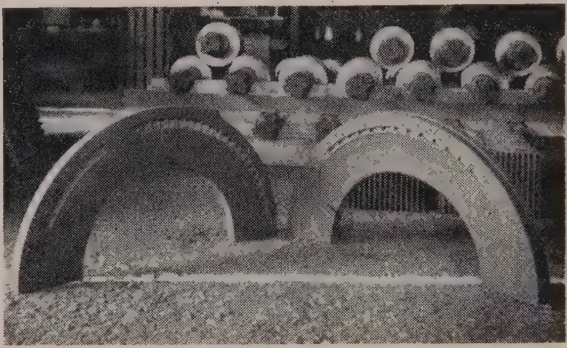

FIG. 9.—TURBINE NOZZLE CASTINGS.

It is in investigation of troubles of this nature that it is advantageous for the engineer and steelfounder to get together; the former approaches the problem from the point of view of how the casting is to be used, and the latter from the point of view of how the casting is to be made.

Co-operative Research in the Future

Whilst progress in the art of steelfounding has, in many cases, been the forerunner of major developments in engineering, the converse is equally true, and the engineer has contributed in no less degree to the improvements made in steelfoundry equipment. Again, it is primarily the demands made by the engineer for material of special qualities which has stimulated foundry development and research. Examples include the chromium-nickel alloys which have the special property of resisting intergranular corrosion, nickel-chrome-molybdenum steel which, after suitable heat-treatment, has a high resistance to shock and is specially suitable for heavy duties, and chromium-carbon steel for castings requiring greater strength, toughness and hardness, as required for gear blanks.

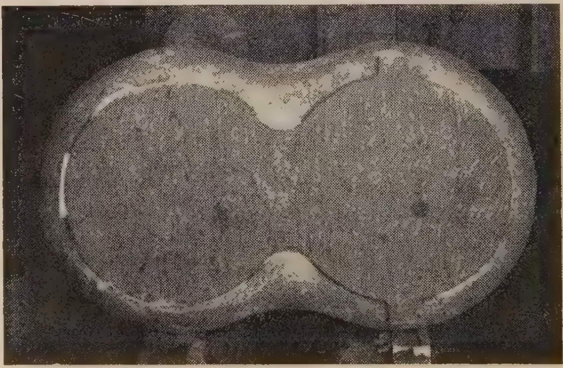

FIG. 10.—DIESEL ENGINE CRANKWEBS.

In marine work rust-resisting steels can be usefully employed for underwater valves and fittings, hydraulic machinery pump components and many other items, as, for example, cabin and bathroom fittings. For these purposes the steelfounder can produce castings in several types of chromium and chromium-nickel stainless steels.

Also available among the special alloy steel castings is a low-carbon steel of high magnetic permeability used in electrical machinery. Special foundry difficulties arise in this case from the necessity of reducing carbon, silicon and manganese to a minimum.

The modern trend towards higher steam temperatures provides the field for carbon-molybdenum steel castings, which have a high limiting creep stress at elevated temperatures.

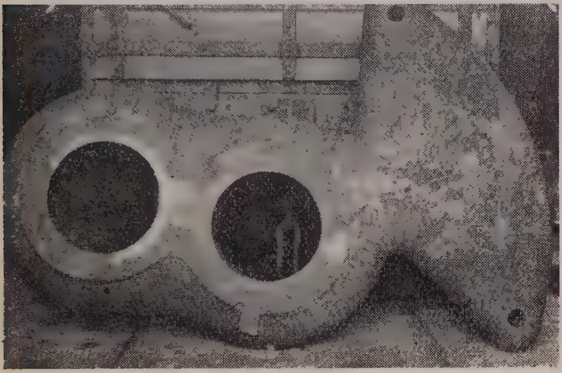

FIG. 11.—DIESEL ENGINE CRANKWEBS.

All these special quality steels, and others which may be called for in the future, have their attendant problems of fluidity, heterogeneity, refractoriness of moulding sand, etc., which the steelfounder has to solve. The problems have often been attacked in the past by trial and error. To-day there is less reason to use these methods, because steelfoundry research has in recent years been properly organised on a co-operative basis under the direction of the Steel Castings Research Committee which is a joint committee of the Iron and Steel Institute and the British Iron and Steel Federation. This committee has addressed itself to a number of cardinal problems associated with the production of steel castings, and several very valuable reports have been issued. Investigations have been made into fluidity and freezing characteristics of alloy systems, the effect of casting temperatures and pouring rates, and the properties of moulding sand.

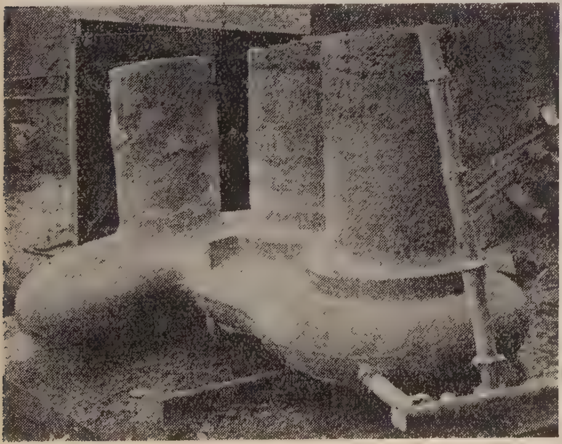

FIG. 13.—METHOD OF CASTING CRANKWEBS. CRANKWEBS AS CAST.

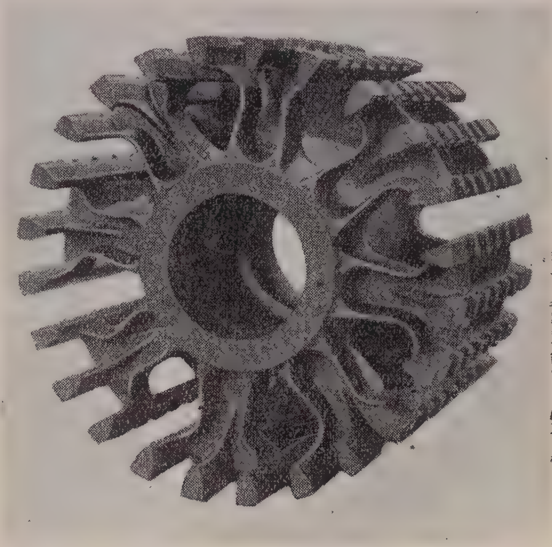

FIG. 12.—ARMATURE ROTOR.

The committee has also given attention to questions relating to inspection of steel castings, including X-ray and gamma-ray examination. Much research work, however, remains to be done, especially in

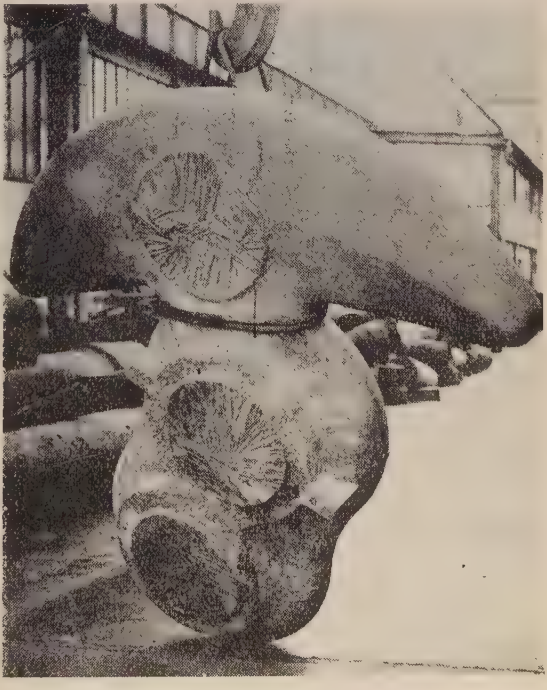

FIG. 14.—CRANKWEBS AFTER REMOVAL OF SHRINK HEADS.

regard to the practical aspect of foundry methods and materials, and their influence on the formation of defects in the casting. It is by no means uncommon for castings to be rejected after considerable machining has been carried out, and there is a feeling amongst engineers that the general run of steel castings is not entirely satisfactory, and that marked improvements could be made.

The Steelfounder and the Welder

A further field for research is in the production of what are called "thin-walled castings," for which there are many uses in engineering. One of the special advantages of mild-steel welded construction is the rational disposition of material, enabling parts to be proportioned in accordance with the contemplated stress distribution. The "massiveness" usually associated with a casting, and which is often required only for foundry purposes, may be quite unimportant in land machinery, but may be undesirable in a marine installation where weight may be more a liability than an asset.

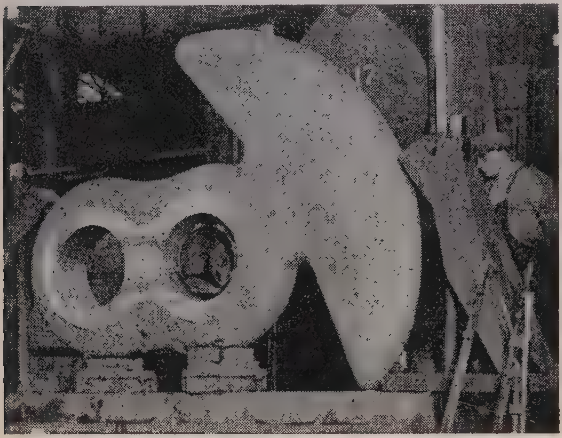

FIG. 15.—CRANKWEBS AFTER BORING.

It is in this direction that the steelfoundry will meet the competition of the welding industry. This competition, in its limited sphere, is entirely healthy. Taking a broader view, the steelfounder and the welder are both essential to engineering progress. It may well be that parts formerly made in cast steel can now be more economically produced as mild-steel "weldings," but there remain many parts for which welding is quite unsuitable, both from the economic and technical standpoints. Castings of special and intricate design as well as repetitive castings of standard design will always be required both in plain carbon and alloy steels, and whilst new methods of manufacture must inevitably arise, they should be accepted in the right perspective, for steelfounding with all its long acquired experience and knowledge, will never lapse into the realm of lost arts. There is in consequence a great need for vigorous prosecution of research, and wider training and education in the industry.

Training and Education

In this connection, I am of opinion that students taking foundry courses at the universities and technical colleges should have at least two years' practical experience of foundry work. Only thus can they assimilate that essential knowledge of the trade in all its aspects which is to be derived from personal contact with the tools and the men who handle them.

I am happy to conclude this lecture with the comment that, whilst for some years Foundry Courses have been included in the curriculum of technical colleges in the U.S.A., France, Belgium, Germany and Italy, in Sheffield University there is available what is probably the most comprehensive scheme for foundry education in the world. A degree course in foundry science is provided in the Faculty of Metallurgy, and throughout the sessions numerous trade lectures are given to foundry operatives. The industry has been fortunate in the work of Prof. J. H. Andrew, who in addition to the organisation of educational facilities, has contributed so largely to general research in the University laboratories.

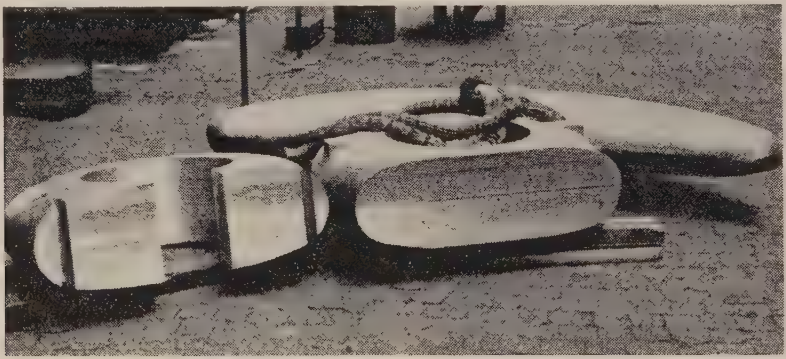

FIG. 16.—SECTION THROUGH CRANKWEB.

It is a matter for congratulation that this Institute has played a major part in establishing these educational facilities both in Sheffield and, originally, in Birmingham.

It may give some satisfaction to the members of this Institute to receive an engineer's unqualified acknowledgment of the great and far-reaching contributions which the steelfounder has made, and continues to make, to all branches of engineering.

Paper No. 768

Report on Copper-Antimony-Nickel Gear Alloy

By MEMBERS OF THE NON-FERROUS SUB-COMMITTEE OF THE TECHNICAL COMMITTEE

FOREWORD

This work was undertaken at the suggestion of the Admiralty following receipt of a report from the Hamilton Gear & Machine Company, of Toronto, Canada, outlining the development of a tin-free gear bronze containing approximately 7.0 to 8.0 per cent. antimony, 1.5 to 2.5 per cent. nickel, balance copper, and claimed to be actually superior to the more conventional alloys employed.[*] Obviously a really good bearing material containing no tin might conceivably be advantageous for many other applications, quite apart from gears, at the present time and therefore the Sub-Committee thought that a useful purpose would be served by conducting one or two trial melts in British foundries in order to gain some idea of the principal characteristics associated with this group of alloys.

TABLE I.—*Solid Phases in the* Cu-Sb *System* (*Shibata*).

Solid phases.	Chemical formula.	Composition (Wt. per cent. Cu).	Crystal Type.
α	—	100—95.3	Face-centred cubic.
β	Cu_5Sb_2 ..	56.71	Body-centred tetragonal.
γ	Cu_2Sb ..	51.08	Simple tetragonal.
δ	Cu_9Sb_2 ..	70.14	Hexagonal.
η	$Cu_{11}Sb_2$ ..	74.17	Orthorhombic.
θ	$Cu_{11}Sb_4$ ..	58.95	Hexagonal.
ϵ	—	Sb*	Hexagonal.

* Possesses a slight solubility range at high temperatures.

Before commenting on the results obtained some mention might be made of the work of previous investigators on the subject. Apart from that published by the Hamilton Gear & Machine Company, available information is scant and most of this deals with the constitution of the alloys. Up to 1940 the equilibrium diagram of the Cu-Sb system seemed to conform to that reproduced in Fig. 1, showing that copper is capable of holding approximately 9.0 per cent. antimony in alpha solid solution at temperatures below 650 deg. C. In the light of more recent research conducted in Japan by Shibata[†] it has been suggested that the solubility of antimony in the alpha phase decreases gradually from 10.4 per cent. at 645 deg. C. to 7.6 per cent. at 488 deg. C., to 6.2 per cent. at 400 deg. C. and to 4.7 per cent. at room temperature as illustrated in Fig. 2. Table I shows the characteristics of the various phases in this system put forward by the above investigator. It should be noted that all the above experiments were conducted on specimens practically free from oxide.

In 1941 the Japanese[‡] gave attention to the copper-antimony-nickel system and for convenience in reference the sections of the equilibrium diagram at the 1 per cent. and 2.5 per cent. nickel levels are reproduced in Figs. 3 and 4.

Apart from the above the only other work which appears to have been done on copper-antimony alloys is an investigation of their resistance to sulphuric acid published in Russia by Pershke and Vasyutovich.[*] In this research the chemical stability of antimony bronzes intended for replacing tin-bronze was investigated. Solid solution alloys containing 4.0 to 5.0 per cent. antimony were prepared and they were found to be only slightly less resistant to sulphuric acid attack than aluminium and tin bronzes.

So far no information has been published on the founding characteristics of this group of alloys and as a first step the Sub-Committee thought it desirable to obtain some idea as to how the alloys would behave in production. Practical tests were undertaken by Mr. J. Arnott, Mr. G. T. Hyslop, Mr. E. J. L. Howard and Mr. F. Hudson on copper containing 7.0 to 8.0 per cent. antimony with and without nickel, and the results from these investigations form the main basis of this report. Generally speaking, it was found that the alloys appear to have good founding properties when correctly melted and poured. Some gas unsoundness in sand castings has been encountered by several investigators, due either to dissolved gases or, more probably, to reaction with the mould surfaces used, but this can be avoided by proper technique. Above 1,100 deg. C. the metal is very fluid and runs readily and should present little difficulty in casting thin sections. Suitable casting temperatures seem to lie between 1,100 deg. C. and 1,200 deg. C., according to the section and type of casting and there is nothing to indicate in these preliminary tests that methods of moulding and running need be any different from those adopted for normal tin bronzes.

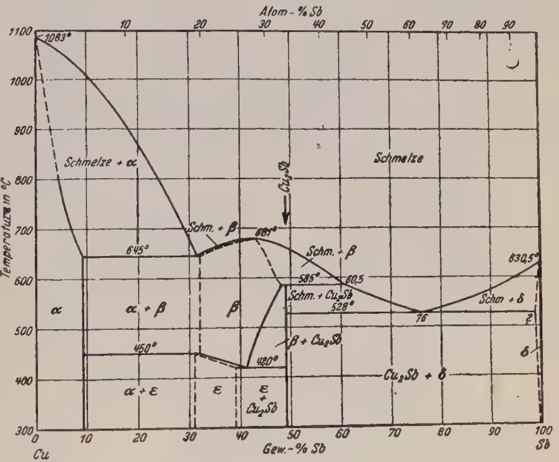

FIG. 1.—EQUILIBRIUM DIAGRAM OF THE CU-SB SYSTEM (HANSEN).

In connection with the alloy containing 7.0 to 8.0 per cent. antimony, 1.5 to 2.5 per cent. nickel, balance copper, recommended by the Hamilton Gear & Machine Company, some difficulty has been found in obtaining an average tensile strength of 14.2 tons per sq. in. from sand castings, but by the use of chills considerably higher values than the quoted figures can be obtained with the composition specified and when modified by the addition of 0.5 to 1.0 per cent. of zinc. Accordingly the use of chills or centrifugal casting might be suggested as preferable methods for production. Chilling does not effect much improvement when there is no nickel present, and in both sand cast and chilled conditions the properties of the nickel-free alloy are much inferior to those obtained on the nickel-containing alloy.

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[*] FOUNDRY TRADE JOURNAL, 1942, LXVIII, 395.

[†] Shibata, N. Nippon Kinzoku Gakkai-Si, 1938, II, No. 3, 108-118; Abs. in Jnl. Inst. Metals, Met. Abs., 1938, V, 476. Nippon Kinzoku Gakkai-Si, 1940, IV, No. 9, 269-289; Abs. in Jnl. Inst. Metals, Met. Abs., 1941, VIII, 31.

[‡] Shibata, N. Nippon Kinzoku Gakkai-Si, 1941, V, No. 1, 12-25; Abs. in Jnl. Inst. Metals, Met. Abs., 1941, VIII, 221.

[*] Pershke, V. K. and Vasyutovich, S. F. Trudy Moskov. Inst. Khim Mashinostroeniya, 1939, No. 7, 109-112; Abs. in Jnl. Inst. Metals, Met. Abs., 1943, X, 14.

An interesting point brought to light in this report is the fact that the copper-antimony-nickel alloy can be hardened appreciably by low-temperature heat-treatment.

Service tests on gear castings made in the copper-antimony-nickel alloy are under way and it is hoped that the results of these will be available when this report comes up for discussion. The Sub-Committee also consider that it will be necessary to determine the corrosion resistance of this alloy in the more common environments. Until such tests have been carried out the alloy is not one which would serve as a general substitute for tin bronze, although it may be quite suitable for certain types of gears and bearing surfaces.

In regard to the scrap problem, phosphor bronze and gunmetal are not particularly sensitive to contamination by antimony and a slight admixture with the copper-antimony-nickel alloy is not likely to be of serious moment with those materials. On the other hand, brasses and managanese bronzes are adversely affected by quite small amounts of antimony; very careful segregation would therefore be called for if the new alloy were to be introduced into a foundry or machine shop handling brasses and manganese bronzes.

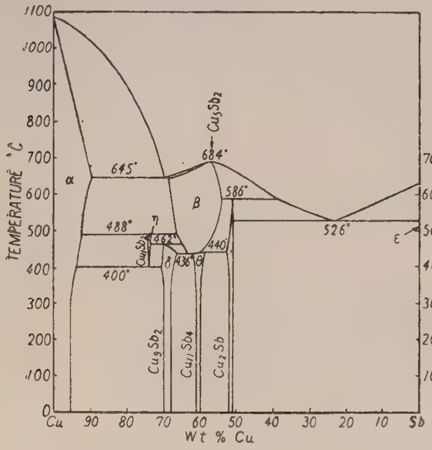

FIG. 2.—EQUILIBRIUM DIAGRAM OF THE CU-SB SYSTEM (SHIBATA).

The report concludes with an appendix giving suggested methods for analysing the type of alloys under review prepared by Mr. R. Woollen and Mr. J. McPheat.

COPPER-ANTIMONY-NICKEL ALLOY

By J. ARNOTT* (Member)

Two melts were made of the composition: Copper, 90.0 per cent.; nickel, 2.0 per cent.; antimony, 8.0 per cent. The nickel was introduced as 30 per cent. cupro-nickel scrap and the first melt was made without any special care during the melting operation. The heads on the castings did not exhibit the normal amount of shrinkage, hence only a few tests were made and it was decided to repeat the melt.

The data obtained from the first melt were as follows:— Contraction, 0.155 in. per ft. *Tensile Tests*:— (A) *Vertical Dry-sand Bar*: Tensile strength, 10.2 tons per sq. in.; elongation, 4 per cent.; Brinell, 72.4. (B) *Horizontal Chill Bar*: Tensile strength, 14.4 tons per sq. in.; elongation, 7 per cent.; Brinell, 75.3. The density of a dry-sand test-bar cast from this melt was 8.45.

In the second melt more care was taken with the melting operation. The copper and cupro-nickel were melted down with 2 per cent. of copper-oxide, and the metal deoxidised with phosphor-copper before adding the antimony. All the test-bar castings showed shrinkage in the heads similar to ordinary gunmetal. The density of a dry-sand test-bar from this melt was found to be 8.60.

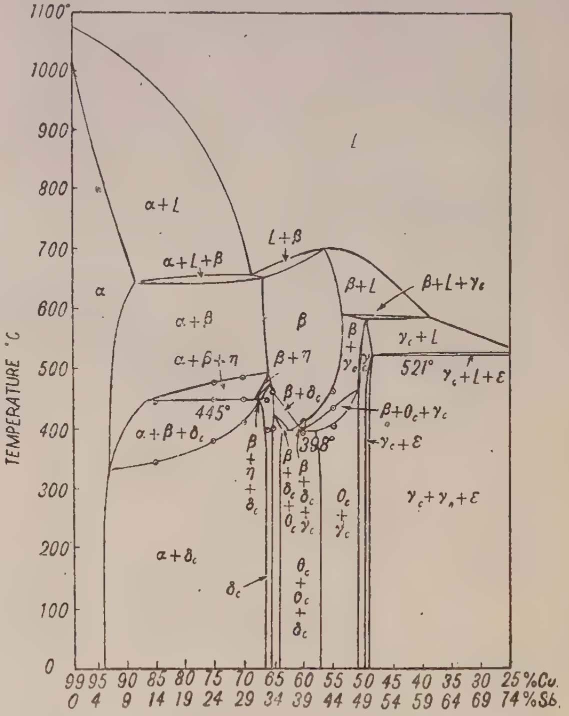

FIG. 3.—EQUILIBRIUM DIAGRAM OF THE CU-SB-NI SYSTEM. SECTION AT 1 PER CENT. NICKEL LEVEL (SHIBATA).

The contraction found was 0.161 in. per ft., which compares with figures of 0.165 in. to 0.175 in. per ft. on A.G.M. The following test figures were obtained:

	Tensile strength. Tons per sq. in.	Elongation. Per cent.	Brinell (1,000kg.)
Vertical dry sand, as cast	10.4	3	90
Vertical dry sand, annealed to 750 °C., ½ hr.	13.0	5	85
I.B.F. shaped bar, 0.564 in.	11.6	3	—
I.B.F. shaped bar, 0.798 in.	8.2	3	—
Chill	14.4	3	94
Chill annealed, 750° C., ½ hr.	14.4	3	92

Two Izod test-pieces were machined from vertical test-bars. Two notches were cut in each and they were arranged to be cut on opposite sides of the test-pieces. The figures all came within the range 4 to 7 ft.-lbs. For comparison it might be added that Admiralty gunmetal cast in a similar fashion gives figures between 7 and 10 ft.-lbs.

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* Messrs. G. & J. Weir & Company, Limited.

Several friction tests were carried out on a reciprocating motion machine which has been used for many years and which has been found to give useful information on problems relating to pump practice. In the first set of trials the antimony alloy was rubbed against a 0.5 per cent. carbon steel in the fully hardened condition (V.P.N. 740). The test was carried out in air, without lubrication, with a load of 50 lbs. per sq. in., at a speed of 160 ft. per minute and for a duration of 100,000 strokes. The antimony alloy showed a wear of 0.003 in., while Admiralty gunmetal under the same conditions showed a wear of 0.089 in.

With the antimony alloy the steel specimen was very slightly scored, whereas with the gunmetal a certain amount of tearing had occurred. No experience is available to allow the value of these tests to be judged in relation to gear applications where lubricant is present. In general, however, it has been found that these friction tests give a useful indication of the suitability of two metals to rub together.

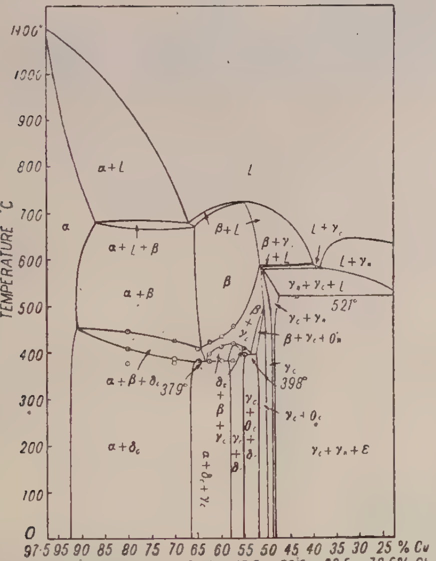

FIG. 4.—EQUILIBRIUM DIAGRAM OF THE CU-SB-NI SYSTEM. SECTION AT 2.5 PER CENT. NICKEL LEVEL (SHIBATA).

The second set of tests was made under the conditions which apply to many parts of pumps. The antimony alloy, and for comparison, a specimen of leaded gunmetal, were rubbed against cast Monel metal in boiling water with a load of 200 lbs. per sq. in.

The test with the antimony alloy was stopped at 50,000 strokes, after which period the specimen had worn 0.156 in. Under the same conditions the leaded gunmetal after 200,000 strokes had worn 0.015 in. It is possibly unwise to compare the new alloy which is lead-free against leaded gunmetal because under the conditions of this test, it has been found that leaded alloys always show reduced wear as compared with lead-free.

The various test-pieces referred to were made as follow:—

Contraction, ¾ in. square, 12 in. long. Cast in Green Sand.—The test-piece is cast against a metal yoke and the contraction afterwards measured by placing the casting inside the yoke and measuring with a taper scale. The *vertical bars* were the type commonly used for aluminium alloy tests, *i.e.*, 1 in. dia., with heads approximately 2¼ in. dia. They were cast in dry sand. The *chill test-pieces* were 1 in. dia., about 7 in. long, cast horizontally. The two sizes of I.B.F. shaped bars were made of the standard sizes and in dry sand. The friction test-pieces were cast in green sand.

TIN-FREE GEAR BRONZE

By W. BROWN* (Member) and E. J. L. HOWARD* (Member)

The effect of casting temperature on the physical properties of a sand-cast copper, antimony, nickel alloy has been determined. The nominal composition of the alloy used is:—Copper, 90.0 per cent.; antimony, 8.0 per cent.; nickel, 2.0 per cent. Two series of test-bars were made: "A" and "B."

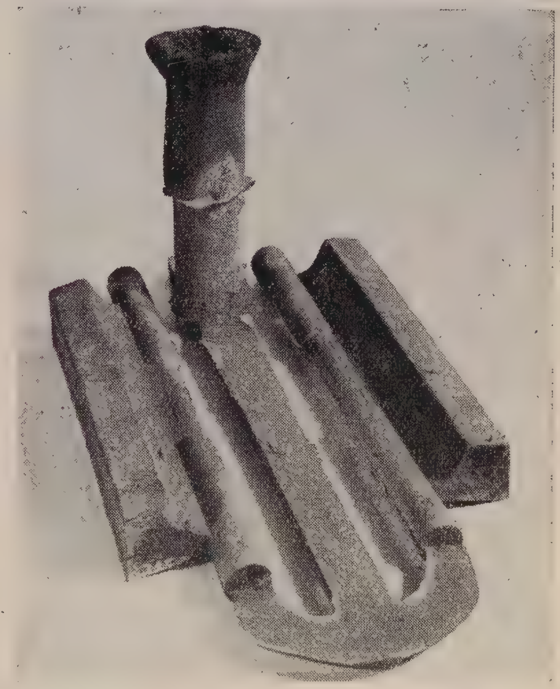

FIG. 5.—TYPE OF TEST-BAR USED BY BROWN AND HOWARD.

Series "A."—Copper, antimony and nickel were alloyed in the proportion of copper 90 per cent., antimony 8 per cent. and nickel 2 per cent. The test-bars cast from it were made in green sand moulds. The copper was melted under a slag, and when completely molten the nickel added. The metal was brought up to 1,300 deg. C. under an oxidising atmosphere and then deoxidised with phosphor-copper. The antimony was then added and the temperature of the metal increased to 1,350 deg. C. before pouring into the ladle. A small quantity of phosphor-copper was again added before casting the test-bars.

Series "B."—The test-bars cast in this series were made in green-sand moulds and dry-sand moulds. The alloy was first prepared in the same manner as

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* Messrs. Mather & Platt, Limited.

Series "A," and then cast into ingots. These were subsequently re-melted under an oxidising atmosphere and deoxidised with phosphor-copper prior to casting.

The metal for both series of tests was melted in a reverberatory furnace, 300 lbs. capacity, and fired with creosote-pitch. During the whole of the period of melting an oxidising atmosphere was maintained in the furnace. Previous experience had shown this alloy was prone to gas absorption, and this could best be prevented by the use of an oxidising atmosphere during melting.

The type of test-bar made is shown in Fig. 5. The bars were cast two in a box moulded approximately to size. They are run with a down runner 1½ in. dia., terminating in a splay to both bars. The splay feeds the bars at the end, and the ingate is the same diameter as the bars. A dummy riser runs the length of and side of each bar. The sands used for making the moulds were those normally employed.

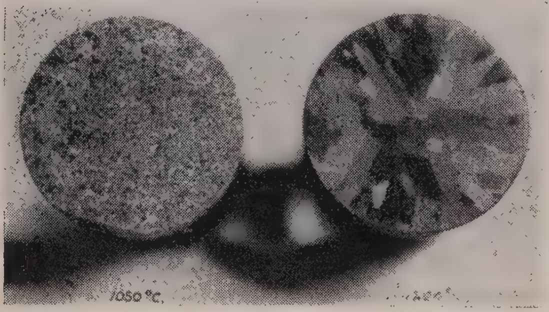

FIG. 6.—EFFECT OF CASTING TEMPERATURE ON MACROSTRUCTURE.

Six boxes of bars were cast for Series "A" and twelve for Series "B," and the pouring temperatures were 1,250, 1,200, 1,150, 1,100, 1,050, 1,000 deg. C. The metal was very fluid and ran easily, with the exception of the lowest temperature, when it was stiff. All the heads had a well-sunk appearance.

Physical and Other Tests

The physical tests carried out on the bars consisted of the determination of the ultimate tensile strength, yield point, elongation, Brinell hardness, Izod impact and density.

The bars were machined down to 0.564 in. diameter. The yield point was taken with a pair of dividers in the usual workshop manner. The Izod test-piece was the standard 10 mm. square bar with three notches, and the tests were carried out on a 120 ft. Avery machine. The hardness tests were taken with the Brinell machine, using a 10 mm. ball and a load of 500 kg. The results obtained on the bars are tabulated in Table II. The figures given are the average of two tests.

The fractures of test-bars cast from 1,100 deg. C. to 1,250 deg. C. inclusive were coarsely crystalline, while those cast at 1,050 deg. C. and 1,000 deg. C. were quite granular. The macroscopic appearance of the bars cast at high temperatures and those at low temperatures showed a marked difference, the grain size of the former being considerably larger than the latter. The macroscopic appearance of two bars cast at 1,200 deg. C. and 1,050 deg. C. respectively is shown in Fig. 6.

The casting temperature does not appear to influence the ultimate tensile strength, yield point, and elongation of the alloy to a very marked degree. The hardness and density rises with the fall in casting temperature. This is typical of most types of bronzes. The Izod figure is low and does not appear to be affected by casting temperature. The difference between the bars cast in green sand and those in dry sand is very little.

The physical properties of the alloy are lower than those usually employed for gears. For castings of similar section to the test-bars, probably the most suitable casting temperature is between 1,100 deg. C. and 1,200 deg. C. This naturally varies with the section and type of casting. The alloy appears to have good founding properties when correctly melted. Above 1,100 deg. C. the metal is very fluid, and runs readily, and should present little difficulty in casting thin sections.

It seems prone to gas absorption, which may result in numerous gas holes just below the casting surface. These defects are not revealed until the casting has been machined. Fig. 7 illustrates this fault. It may be overcome by melting under a fairly strong oxidising atmosphere and reducing with phosphor-copper. The casting temperature should not be too low. A number of small castings have been successfully made with this alloy, and there is nothing to indicate that the methods of moulding and running need be any different from those adopted for normal tin bronzes.

TIN-FREE GEAR BRONZE

BY G. T. HYSLOP* (Member) and R. F. HUDSON* (Member)

Castability and Melting

Copper, nickel and antimony were ingotted in the following proportions: 7.5 per cent. antimony, 2.0 per cent. nickel, and 90.5 per cent. copper. Commercial antimony was used plus Monel bar end scrap (Si trace) and B.S. copper ingots; these were ingotted and the ingots used for all the following melts, together with returned heads and gates.

Sand, chill and centrifugal castings were all made. In the case of sand and centrifugal castings no trouble was observed, the metal being fluid and easy running, most of the castings being poured at about 1,200 deg. C. When the temperature was lowered to 1,150 deg. C. a skin appeared on the metal surface and the first traces of sluggishness were seen. The metal was clean, and top pouring was employed to ensure progressive solidification. In the case of the chill-cast sticks, minute gas or blowholes were present in all the small diameters, suggesting that the alloy solidified so rapidly that air and mould gases were trapped. This is per-

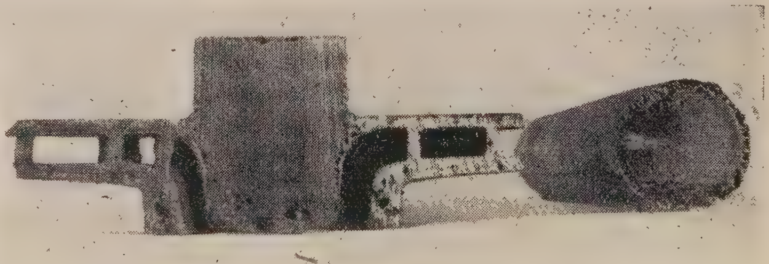

FIG. 7.—DEFECTS DUE TO GAS ABSORPTION.

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* Phosphor Bronze Company, Limited.

haps one of the reasons for the low physical properties of this material shown in Table IV.

The contraction of this alloy observed in green-sand castings was approximately 0.1 in. per ft. The castings had a good finish in green and dry sand, and no metal penetration occurred.

Both forced-draft and natural-draft furnaces were used in melting, and undoubtedly the best results were obtained from oil-fired and coke-fired forced-draft furnaces. No excessive oxidation or gas absorption occurred, and reasonable physical properties were maintained. On the other hand, when natural-draft coke-fired furnaces were used in conjunction with a slightly reducing atmosphere "spewing" occurred, the evolution of hydrogen forcing the molten metal to expand in the runner basin. Even when an oxidising flux (containing manganese dioxide) was used there was still no tendency for the heads to sink. Many of the alloy's characteristics were in marked similarity with 90/10 tin-bronze.

TABLE II.—*Properties of Test Bars.*

Casting temperature deg. C.	Ultimate tensile strength. Tons per sq. in.	Yield point. Tons per sq. in.	Elongation, per cent.	Brinell hardness.	Density	Izod ft./lbs.
			Series "A." *Green Sand Test Bars.*			
1,250	11.5	9.6	4	69	8.58	3—5
1,200	12.2	9.8	5	69	8.53	3—5
1,150	14.2	10.1	11	76	8.59	3—5
1,100	12.7	9.04	4	80	8.58	3—5
1,050	12.7	10.7	4	86	8.67	2—4
1,000	9.6	8.6	1	86	8.66	1—2
			Series "B." *Green Sand Test Bars.*			
1,250	12.4	8.4	5	63	8.51	3—6
1,200	12.6	8.4	8	69	8.42	3—5
1,150	12.7	9.1	7	70	8.53	3—5
1,100	13.0	8.9	5	83	8.48	3—5
1,050	12.4	8.2	4	86	8.68	1—3
1,000	9.2	8.1	2	86	8.58	1—3
			Series "B." *Dry Sand Test Bars.*			
1,250	11.1	8.3	5	76	8.42	4—6
1,200	11.9	7.8	6	76	8.49	3—6
1,150	11.7	8.2	6	80	8.44	5—7
1,100	11.2	8.4	5	82	8.54	3—5
1,050	11.1	7.9	2	80	8.67	2—4
1,000	9.5	8.0	1	84	8.69	1—2

See Table III for Analyses

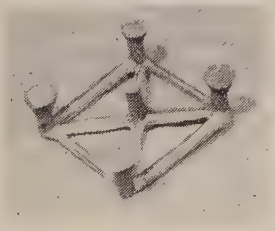

FIG. 8.—SHOWING METHOD OF CASTING TEST-PIECES.

Physical Properties

Table IV shows the results obtained when cast in sand, statically chill cast and centrifugally cast. It will be observed that in contradistinction to spun phosphor bronze the results of this alloy in comparison to sand castings give lower figures except in the case of density and Brinell hardness. Close agreement was found with the published test figures and also with the Hamilton Gear & Machine Company's statement regarding the lack of advantages associated with chill-cast gear blanks over sand cast. The photomicrographs indicate that chill and centrifugal castings have more, and also a finer distributed bearing constituent. (Blue coloured constituent most probably a beta solid solution.)

The Izod values, and in fact all the physical properties with the exception of yield point and Brinell hardness were found to be slightly lower than the equivalent copper-tin-phosphorus alloys. However, the figures shown are high enough to ensure a commercial value and use for this alloy.

TABLE III.—*Analyses of Test Bars.*

	Series "A."	Series "B."
	Per cent.	Per cent.
Copper	89.79	89.96
Antimony	8.13	7.95
Nickel	1.90	1.86
Lead	0.06	0.09
Phosphorus	0.01	0.01

The authors' firm is now trying out in service both sand and centrifugally cast gear wheels, and from these tests it is hoped to obtain valuable information. Some pressure castings were also manufactured (pipe castings with $\frac{1}{4}$-in. wall section), and these, on testing with compressed air, were found quite satisfactory at 100-lb. pressure.

Table IV gives the test results obtained co-related to analysis and pouring temperatures for sand, chill and spun castings. For comparison are given figures for a phosphor-bronze alloy. Fig. 8 illustrates the method used for making the sand-cast test-pieces, utilising a central downgate with four ingates running into risers at each end of the test-pieces (Eash pattern), producing two tensile test-bars and two Izod bars. The chill-cast bars were machined from a ⅞-in. dia. 2-ft. long cast stick, and the centrifugally-cast pieces cut from small gear blanks.

Micro-Structure

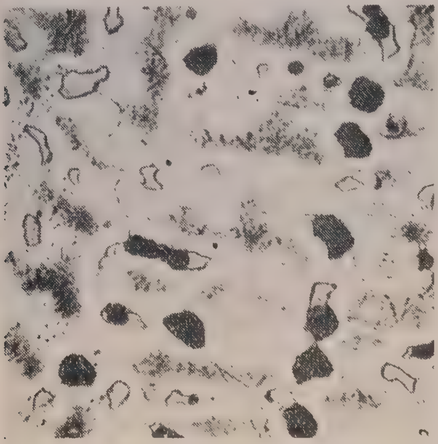

FIG. 9.—SAND-CAST TEST-PIECE, SHOWING BLUE CONSTITUENT OF BETA SOLID SOLUTION, CONTAINING APPROX. 30 TO 40 PER CENT. SB, SURROUNDED BY CORED ALPHA SOLID SOLUTION. (× 300.)

Fig. 9 to 13 show the micro-structure of sand and centrifugally cast copper-antimony-nickel alloy at various magnifications. Two phases are very prominent. Firstly, a cored structure is present similar to that in bronze, probably an alpha solid solution of copper-antimony and nickel. This phase at low magnifications has a light fawn appearance through which is dimly seen the cored structure.

The second main constituent is dispersed blue islands of a beta solid solution containing approximately 30-40 per cent. antimony, surrounded by the cored alpha solid solution. This beta phase is definitely the hard bearing constituent. Fig. 11 shows a centrifugally cast specimen with much more beta solid solution present, indicating better bearing properties with this method of casting. There are therefore all the attributes of a typical bearing alloy present, a fairly soft and yielding matrix included in which are isolated particles of a hard bearing compound.

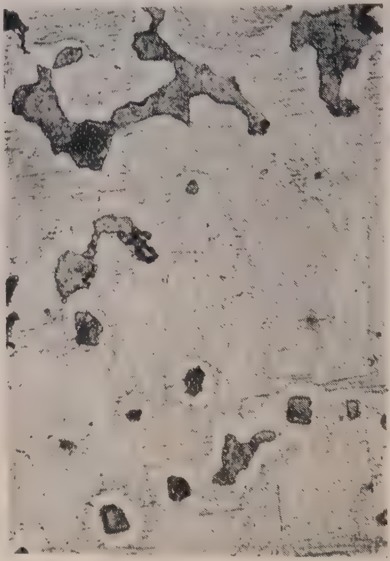

FIG. 10.—SAND-CAST TEST-PIECE, SIMILAR TO FIG. 9 (× 500). BOTH FIGS. 9 AND 10 SHOW SLIGHT TRACES OF POROSITY, THIS BEING DUE TO THE LONG FREEZING RANGE.

Doubt arises regarding the presence of a third phase, as claimed by the originators of the alloy, but personal opinion is that this alloy contains only two. A third phase sometimes seems to be visible, but it is suggested that perhaps this is due to over-etching. The etching medium employed was the usual ferric chloride solution as used for brass and gunmetal. The beta solid solution (containing 30-40 per cent. antimony) also appears at the grain boundaries forming a eutectic solidifying at 640-650 deg. C. Black specks may be seen in this constituent, which are probably oxide

TABLE IV.—*Mechanical Properties of Copper-Antimony-Nickel Alloy in Comparison with Phosphor Bronze*

Alloy.	Method of casting.	Density.	Yield point, tons per sq. in.	U.T.S. tons per sq. in.	Elong. per cent. on 2 in.	Brinell hardness No.	Izod ft.-lb.	Pouring temperature, °C.	Remarks.
Per cent. 7.32 Sb 1.80 Ni 90.75 Cu	Dry sand	8.16	11.2	14.7	9	69—82	3—5	1,160	—
	Green sand	8.17	10.5	13.3	5	—	3—5	1,200	Slightly segregated.
	Chill	8.55	10.0*	10.5*	2	81—89	1.5 to 2.5	1,200	Fine grain.
	Cent.	8.58	11.6	14.0	3	101	1—2	1,190	Vert. cast fine grain.
		—	15.2	18.2	1	—	—	—	Horiz. cast fine grain.
11.05 Sn 0.28 P 88.67 Cu	Dry sand	8.37	10.0	17.2	12	85	4—6	1,100	—
	Cent.	8.71	12.2	19.8	10	105	—	1,140	—

* Average of three tests all bars slightly flawed.

inclusions. A report from Dr. W. T. Pell Walpole, of Birmingham University, on microstructure is appended.

Due to the long freezing range of this alloy care must be taken to ensure rapid solidification in order to obtain good bearing properties and sound castings.

Machining is quite good, tools lasting a little longer than with tin-bronzes. This alloy is readily repaired by electric arc-welding methods using copper-tin flux covered electrodes. Several sand cast bushes were machined and subjected to a tinning operation with perfectly satisfactory results.

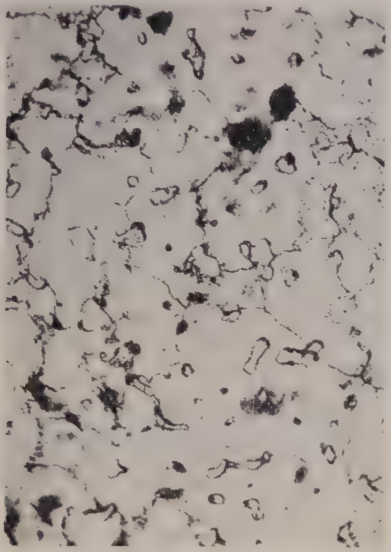

FIG. 11.—CENTRIFUGALLY-CAST TEST-PIECE, SHOWING SIMILAR STRUCTURE, BUT THE BLUE BETA CONSTITUENT BEING MUCH MORE FINELY DISTRIBUTED AND IN LARGER AMOUNTS (× 500).

Further Tests on Tin-Free Gear Bronze

Other investigators having experienced trouble in the melting of this alloy, some casts were made to determine the correct method of avoiding gas absorption. As zinc prevents this in gunmetals it was decided to try a small addition of this metal, followed by deoxidation with phosphor copper. This treatment gave good results, and many heats have since been made from both oil-fired and natural draft coke-fired pit furnaces, resulting in gas-free castings, although oil-fired furnaces are preferred because of their uniform controlled atmosphere. Fig. 14 shows the appearance of a good head from a sand cast 2½ in. diameter solid bar following the use of this technique. The procedure is as follows:—

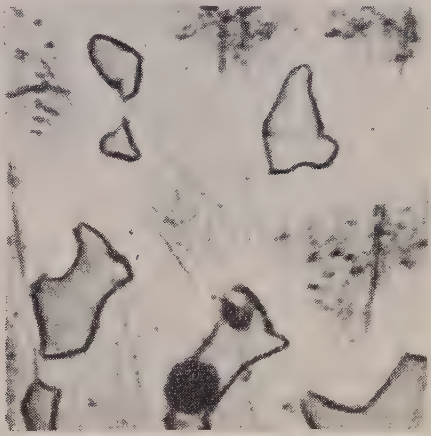

FIG. 12.—SAND-CAST TEST-PIECE, SHOWING BLUE ISLANDS OF BETA SOLID SOLUTION EMBEDDED IN ALPHA SOLUTION (× 1,000).

"Scrap or ingot metal is charged with 0.5 per cent. zinc; no flux is used, the metal being melted as quickly as possible in a slightly oxidising atmosphere. Immediately the metal reaches a heat slightly in excess of pouring temperature, it is withdrawn from the furnace and deoxidised with 0.05 per cent., P-Cu (10 per cent. P), the pouring temperature of the aforementioned casting being 1,180 deg. C. It has been found even with this method that "stewing" burns out the zinc and "gassing" tends to occur in such cases, especially in natural draft furnaces where the atmosphere tends to vary. This, as previously stated, is the reason why, wherever possible, the use of oil-

TABLE V.—*Showing how Temperature and Furnace Atmosphere Affect the Mechanical Properties of Cu-Sb-Ni Alloy.*

Alloy.	Flux.	De-oxd.	Temperature of metal.	Pouring temperature.	Mechanical properties.			Furnace atmosphere gas analysis.		Appearance of head.
					Y.P. tons per sq. in.	U.T.S. tons per sq. in.	Elong. per cent.			
Per cent. 7.5 Sb 2.0 Ni 91.5 Cu	None ..	0.05 per cent. P	1,220° C.	1,200° C.	10.2	13.6	7	CO$_2$ CO O H W.V.	Per cent. 12.3 0.7 1.8 Nil 0.0014	Sunk.
Do.	None	0.05 per cent. P	1,300° C.	1,200° C.	9.7	11.2	5	CO$_2$ CO O H W.V.	Per cent. 7.2 2.2 1.2 Nil 0.0014	Spewed.

The above results are obtained on materials made from ingots and scrap plus 0·5 per cent. Zn and melted in natural-draft coke-fired crucible furnaces

TABLE VI.—*Effect of Heat Treatment on the Mechanical Properties of Copper-Antimony-Nickel Alloy.*

No.	Alloy.	Heat treatment.	Mechanical properties.				
			Y.P. tons per sq. in.	U.T.S. tons per sq. in.	Elong. per cent.	Min. B.H. No.	Maximum B.H. No.
1	Sb-Ni-Cu Sand cast	None	11.45	13.5	7	70	80
2	Do.	3 hrs. at 450° C. Cooled in air	13.6	15.2	3.5	80	103
3	Do.	5 hrs. at 450° C. Cooled in air	—	—	—	85	—
4	Cent. cast	None	11.6	14.0	3	101	116
5	Do.	3 hrs. at 450° C. Cooled in air	14.8	15.7	2.5	114	143
6	Chill cast..	None	—	—	—	85	111
7	Do.	3 hrs. at 450° C. Cooled in air..	—	—	—	101	163

fired forced draft furnaces is preferred. Up to date with this treatment 100 per cent. good castings have been obtained. Table V shows how excess temperature and a slightly less oxidising atmosphere alters the density and physical properties of this alloy."

It was also considered that heat-treatment may have some effect on the properties of this alloy, and several tests were carried out on chill, centrifugal and sand-cast specimens in this direction. It was found that after heat-treating at 450 deg. C. there was an increase in both tensile and Brinell, with a reduction in elongation. The increase in hardness is interesting because of the possibility of this leading to an improvement in bearing characteristics. Service tests are accordingly under way on specimens in the "as cast" and heat-treated condition with the view of obtaining information in this direction. Table VI shows the effect of heat-treatment on the mechanical properties of the copper-antimony-nickel alloy in sand, chill and centrifugally cast condition. Fig. 15 shows photomicrographs of sand cast and heat-treated specimens at 500 magnifications.

TABLE VII.—*Showing Properties of Sand Cast Alloys of Modified Composition.*

Alloy.	Mechanical properties.					
	Y.P. tons per sq. in.	U.T.S. tons per sq. in.	Elong. per cent. on 2-in.	B.H. No.	Izod. Ft.-lbs.	Remarks
Per cent. 7.5 Sb 2.0 Zn 90.0 Cu	8.4	8.6	3	102	5	Segregated fracture.
8.0 Sb 92.0 Cu	9.6	11.6	5.5	99	4	Dendritic and segregated fracture

Tests have also been conducted on alloys free from nickel, and it was found that this modification resulted in a considerable reduction in mechanical properties as shown in Table VII.

This alloy appears to have favourable possibilities for the production of thin sectioned sand cast bearing bushes and gear blanks and for the manufacture of heavier sectioned gear blanks by the centrifugal process. The results of service tests are, however, required to confirm this statement. Further work is in progress to determine the physical properties of the alloy in the centrifugally cast condition.

Report on the Micro-Structure of an Alloy Containing 7.5 per cent. Antimony, 2.0 per cent. Nickel, balance Copper

BY DR. W. T. PELL WALPOLE

The microstructure consists of: (1) A heavily cored alpha (Cu-rich) solid solution varying in the etched

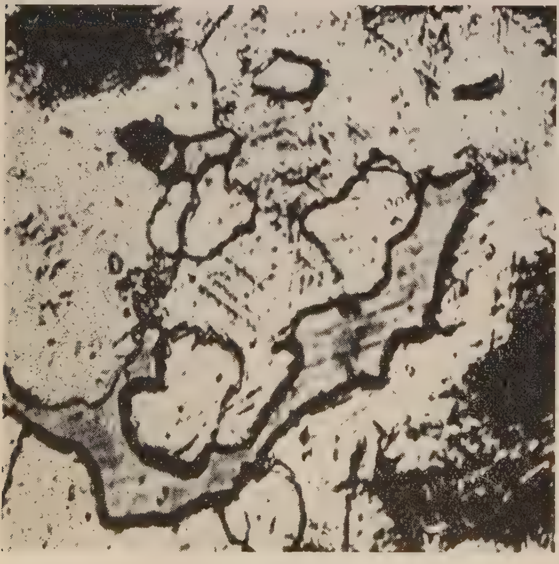

FIG. 13.—SAND-CAST TEST-PIECE, EXACTLY AS FIG. 12 BUT MORE DEEPLY ETCHED (× 1,000).

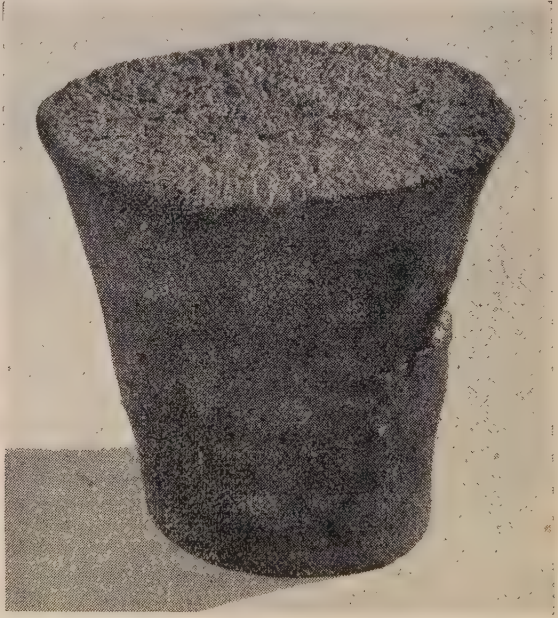

FIG. 14.—TYPICAL APPEARANCE OF FEEDING HEAD FROM GOOD CU-SB-NI ALLOY CASTING.

condition from dark brown at the cores to pale straw at the boundaries; (2) pools of a second blue constituent (probably the beta of the Cu-Sb system with some Ni in solution) at the alpha boundaries. The beta is harder than the alpha, and presumably is intended to act as the usual "hard particle constituent" in the bearing. At high magnifications the beta has a marbled appearance, which probably indicates a partial completion of the reaction β-ε which occurs at about 450 deg. C. It should be noted also that with fairly deep etching the alpha develops a sub-boundary structure, which may give the impression that there are actually two yellow phases present. It is believed, however, that this is purely an etching effect. The whole structure is rather porous (pinhole shrinkage cavities), no doubt due to the very long freezing range (about 400 deg. C.). These features are shown in the photomicrographs taken at 300 and 1,000 magnifications respectively.

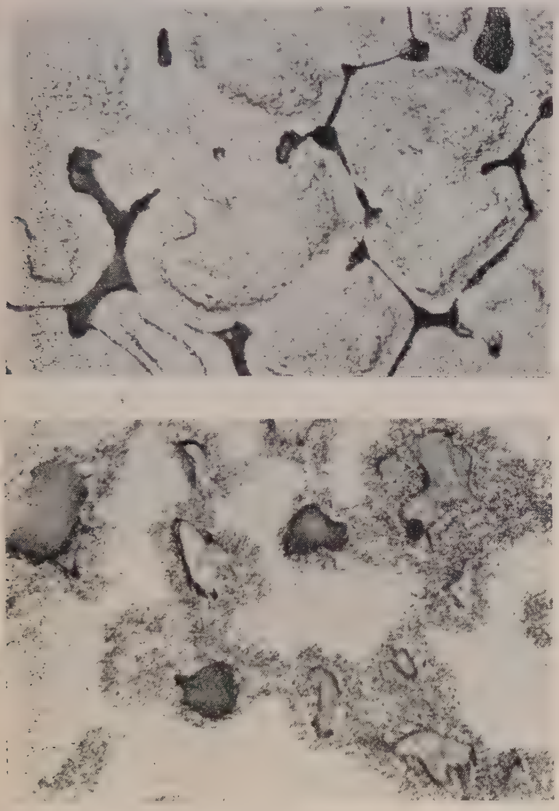

Fig. 15.—Showing the Effect of Heat-Treatment on the Microstructure of Cu-Sb-Ni Alloy.
Top: Sand Cast (× 500).
Bottom: Sand Cast and Heat Treated 3 hrs. at 450 deg. C., Cooled in Air (× 500).

The above analysis is in accord with the interpretation of the constitutional system Cu-Sb-Ni, having regard to the lack of equilibrium due to the specimen being in the "as cast" condition. Copper and nickel are mutually soluble, each can dissolve (in equilibrium) about 8-9 per cent. Sb, and with high Sb content each form a beta phase. Alloys containing less than 30-45 per cent. Sb will form (at high temperatures) only two phases alpha and beta. Both beta phases undergo transitions at lower temperatures. An alloy containing $7\frac{1}{2}$ per cent. Sb, 2 per cent. Ni would, on equilibrium, be entirely alpha, but with normal rates of cooling should consist of heavily cored alpha with a certain amount of beta, which may be partially changed to ε during subsequent cooling.

The liquidus of the alloy is approximately 1,020 deg. C., the solidus approximately 650 deg. C.

THE MECHANICAL PROPERTIES OF COPPER-ANTIMONY-NICKEL GEAR BRONZES

By A. Dunlop* (Associate Member) and Frank Hudson* (Member)

A number of melts have been made of nominal composition, 7 to 8 per cent. antimony, 1.5 to 2.5 per cent. nickel, balance copper, to confirm the mechanical properties claimed by the Hamilton Gear & Machine Company for the copper-antimony-nickel alloy. The effects of adding 0.5 to 1 per cent. of zinc to the nickel-containing alloy, and of substituting 0.5 to 1.0 per cent. of zinc for the 1.5 to 2.5 per cent. of nickel, have been briefly studied. Table VIII contains a summary of the results obtained on sand and chill cast samples of these alloys.

The Hamilton Gear & Machine Company claim that no advantage is obtained by chilling and state the average mechanical properties of the sand-cast alloy to be 8.5 tons per sq. in. yield point, 14.2 tons per sq. in. tensile strength, and 7.5 per cent. elongation. It will be noticed that in the sand-cast condition such values have not been attained, but by the use of chilling considerably higher values than the quoted figures can be obtained in the alloy of specified composition and when modified by the addition of a small amount of zinc. Chilling does not effect much improvement when there is no nickel present and in both sand-cast and chilled conditions the properties of the nickel-free alloy are much inferior to those obtained on the nickel-containing alloy.

The structure of the alloy is duplex, similar to that of tin bronze. Figs. 16 and 17 at magnifications of 100 and 500 respectively show the structure of a sand-cast sample containing 7.98 per cent. antimony and 1.70 per cent. nickel. The structure which has been developed by etching in a ferric chloride solution acidified with hydrochloric acid, consists of pools of a blue constituent, probably the β of the copper-antimony system in a matrix of cored α solid solution. Fig. 18 at a magnification of 100 shows a chill-cast sample of similar composition. It will be noted that chilling has resulted in the β phase being more finely divided and not forming such continuous films around the dendrites while there is less coring of the α matrix. Some porosity is evident in both samples, due, no doubt, to the very wide freezing range of the alloy.

Details of Melts

The following are the details of the various melts made: All the melting was conducted in an oil-fired crucible furnace. Remelted cathode copper and a commercial brand of antimony were used and the nickel was added either as 50/50 copper-nickel shot or 80/20 copper-nickel scrap.

For the first melt the copper and 50/50 shot were melted with the addition of an oxidising flux. The melt was deoxidised with 0.025 per cent. of phosphorus added as 10 per cent. phosphor copper and the antimony added. Before pouring a further addition of 0.025 per cent. of phosphorus was made. From this melt a four-bar pattern tensile bar casting, a four-bar pattern Izod bar casting and four keel block castings were poured, the casting temperature being 1,200 deg. C. The four-bar pattern tensile bar casting consisted of four cast-to-shape bars in the form of a square with feeders at each corner, the feeders being connected by two cross runners to a central downgate. The test-pieces were 6 in. long and ¾ in. diameter in the gauge length as cast. Standard 0.564-in. diameter tensile test-pieces were machined from these. The Izod bar casting was of similar design, the as-cast dimensions of the bar being ⅝ in. diameter by 5 in. long. From two of these blanks standard 0.45-in. diameter notched Izod test-pieces were machined. The keel block bars were 1⅛ in. by 1⅜ in. by 8 in. long, with a feeding block of 2½ in. square section along their full length. Two of the keel block bars were made entirely in sand, the other two had the test portion chilled with ½ in. thick steel plate. No separate runner was used for these castings, the feeding block being open and the mould filled by direct pouring.

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* Research and Development Department, Mond Nickel Company Limited.

The sand employed was not of the type normally employed for copper base casting alloys, being a synthetic sand of silica base bonded with bentonite and containing 3 to 4 per cent. of coal dust. Satisfactory results have been obtained when using this sand on a wide range of non-ferrous alloys, including tin bronzes of all types, and no trouble was expected on using this sand for the copper-antimony-nickel alloy.

The results obtained on the above castings are given in Table IX.

A second melt was made by melting risers, etc., from melt 1 with an oxidising flux and an addition of 0.05 per cent. of phosphorus made before pouring four keel block bars, two entirely in the above type of sand and two with the test portion chilled, the casting temperature being 1,180 deg. C. In this instance and in all subsequent keel block castings made the metal was introduced into the mould *via* a downgate connected to one end of the casting by an ingate leading into the test portion. All these castings were "gassed" and the feeders "spewed" badly, particularly the castings without the chills. Excess metal poured into an iron ingot mould, however, sunk well.

A third melt similar to the second melt was made and behaved similarly. Immediately after pouring all

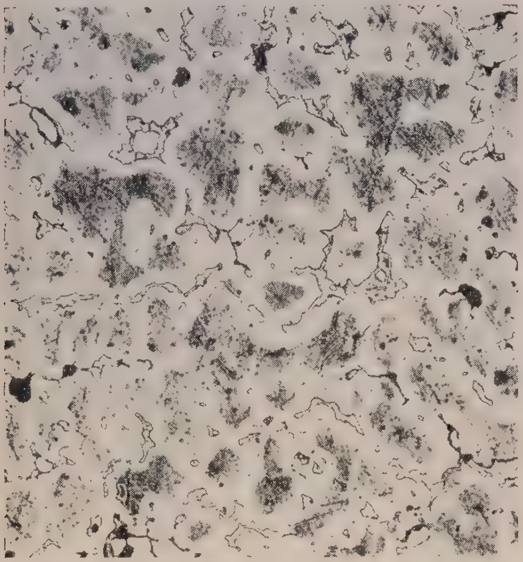

FIG. 16.—SAND-CAST SAMPLE (× 100).

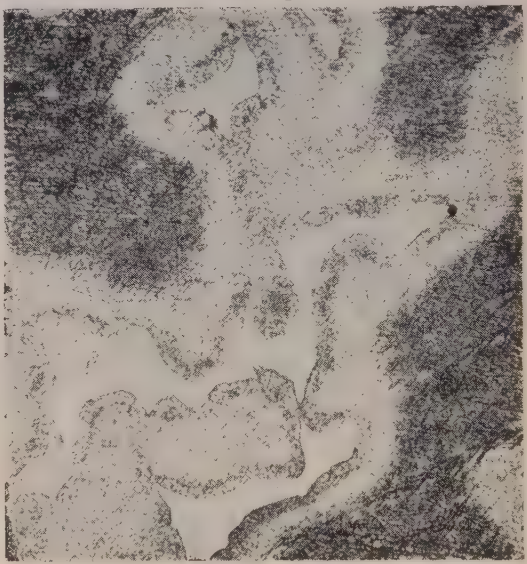

FIG. 17.—SAND-CAST SAMPLE (× 500).

TABLE VIII.—*Summary of Mechanical Properties of Sand and Chill Cast Alloys of Specified Composition and of Alloys Modified by the Addition of Zinc and Omission of Nickel.*

Nominal composition.	7—8 per cent. Sb, 1.5—2.5 per cent. Ni, Balance Cu.		7—8 per cent. Sb, 1.5—2.5 per cent. Ni, 0.5—1 per cent. Zn, Balance Cu.		7—8 per cent. Sb, 0.5—1 per cent. Zn, Balance Cu.	
	Sand cast (5)	Chill cast (5)	Sand cast (4)	Chill cast (3)	Sand cast (3)	Chill cast (3)
0.2 per cent. proof stress, tons per sq. in.	7.1—8.2	9.6—12.2	7.0—9.0	9.8—10.9	6.4—6.8	8.0—8.8
Yield point (0.5 per cent. elongation under load) tons per sq. in.	7.8—8.8	10.4—13.5	7.6—9.9	10.4—11.5	7.0—7.6	8.6—9.6
Tensile strength, tons per sq. in.	9.7—11.0	15.8—19.5	9.1—11.8	16.2—18.9	8.0—8.8	8.7—11.8
Elongation per cent. on $4\sqrt{\text{area}}$	1—4	4—21	3—4	9—12	1—3	2—4
Izod impact, ft.-lbs.	3.5—4.5	—	—	—	—	—
Brinell hardness, 10/1,000/15	63—82	73—98	72—79	81—90	65—69	71—79

Figures in brackets refer to number of bars tested.

the feeders were level, but a few minutes later, the casting without chills "spewed" badly.

At this stage, it was thought that the melting technique was at fault and a fourth melt was made using new metal. The copper and cupro-nickel were melted with ½ per cent. of copper oxide and 1 per cent. of manganese ore and deoxidised with 0.05 per cent. of phosphorus, the antimony was added followed by 0.5 per cent. of zinc. Four keel block castings, two with and two without chills, were poured at a temperature of 1,180 deg. C. All the castings were "gassed" and the castings without the chills "spewed" badly.

A fifth melt was made using the risers from melt 4. No flux was used, and the furnace burner was set to give oxidising conditions. On melting, some bubbling was noted. The oil was turned off and the melt allowed to cool slowly in the furnace until pasty. At this stage bubbling had ceased and the melt was quickly raised to 1,100 deg. C. and four keel block bars poured, two with chills and two without. The castings with chills sunk slightly, the others rose. On cutting off the test portions, the castings with the chills were sound while the others had many gas holes just below the skin (see Fig. 19, which illustrates the unsoundness).

Properties of Chilled Bar

The following properties were obtained from the chilled bar from this melt:—

Analysis.—Copper, 91.3 per cent.; antimony, 7.4 per cent.; nickel, 1.27 per cent.

0.2 per cent. proof stress, tons per sq. in.	9.6	9.6
Yield point (0.5 per cent. elongation under load) tons per sq. in.	10.2	10.1
Tensile strength, tons per sq. in. ..	19.5	18.6
Elongation per cent. on 4√ area ..	21	14
Brinell hardness (10/1,000/15) ..	73	

TABLE IX.—*Mechanical Properties of Alloy of Composition* 89.45 *per cent. Copper*, 8.03 *per cent. Antimony*, 2.42 *per cent. Nickel.*

Type of tensile casting.	0.2 per cent. proof stress. Tons per sq. in.	Yield point (0.5 per cent. elongation under load). Tons per sq. in.	Tensile strength. Tons per sq. in.	Elongation, per cent. on 4√ area.	Brinell hardness, 10/1,000/15.	Izod impact. Ft.-lbs.
Sand cast to shape ..	7.6†	8.1	11.0	4	—	4.0 3.5 } 4.0 4.5
Sand cast to shape ..	8.2	8.8	9.7	2	63	4.5 4.5 } 4.5 4.0
Sand cast to shape ..	8.0	8.8	10.1	2	—	
Keel block bar sand cast	7.1	7.8	10.0 6.4*	3 2	—	—
Keel block bar with test portion chilled ..	12.2‡ 11.4	13.5 12.0	17.9 13.6*	4 2	— 98	— —

* Flaw in fracture. † Density 8.04. ‡ Density 8.76.

TABLE X.—*Effect of Casting Temperature and Modifications to the Composition on the Mechanical Properties of the Copper-Antimony-Nickel Alloy.*

Nominal composition.	Casting temperature. ° C.	Mould.†	0.2 per cent. proof stress. Tons per sq. in.	Yield point (0.5 per cent. elongation under load). Tons per sq. in.	Tensile strength. Tons per sq. in.	Elongation, per cent. on 4√ area.	Brinell hardness, 10/1,000/15.
Antimony, 7—8 per cent. .. Nickel, 1.5—2 per cent. .. Cu, balance ..	1,180	Chill ..	8.8	9.5	13.3*	6	81
	1,150	,, ..	9.8	10.4	15.8	7	82
	1,180	Sand ..	6.4	6.9	7.2*	3	75
	1,080	,, ..	8.0	8.7	9.8	1	82
Antimony, 7—8 per cent. .. Nickel, 1.5—2 per cent. .. Zinc, 0.5—1 per cent. .. Cu, balance ..	1,180	Chill ..	9.8	10.4	16.2	9	81
	1,110	,, ..	10.9	11.5	18.9	10	90
	1,000	,, ..	9.8	11.0	18.2	12	84
	1,180	Sand ..	7.0	7.6	9.1	4	73
	1,110	,, ..	8.4	9.1	10.9	3	77
	1,100	,, ..	7.6	8.3	10.9	4	72
	1,000	,, ..	9.0	9.9	11.8	3	79
Antimony, 7—8 per cent. .. Zinc, 0.5—1 per cent. .. Cu, balance ..	1,190	Chill ..	8.0	8.6	8.7	3	71
	1,100	,, ..	8.8	9.6	10.4	2	77
	1,100	,, ..	8.8	9.5	11.8	4	79
	1,190	Sand ..	6.4	7.0	8.0	2	65
	1,100	,, ..	6.8	7.6	8.8	3	69
	1,070	,, ..	6.4	7.2	8.1	1	68

* Flaw in fracture. † All castings of the keel block type.

In all of the above melts it was noted that no matter how badly a casting "spewed" excess metal poured into a cast iron ingot mould invariably sunk. This seemed to indicate that the gassing trouble might be due to the presence of coal dust in the sand. The subsequent melts were made in sand free from coal dust, and no further trouble due to "spewed" castings was encountered.

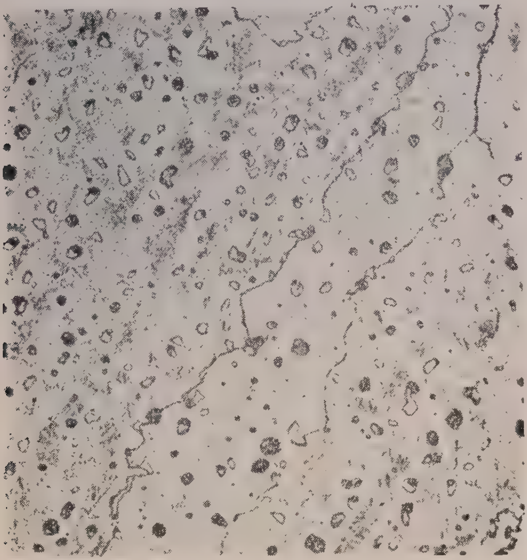

Fig. 18.—Chill-Cast Sample (× 100).

Figs. 16-18.—Microstructure of Sand- and Chill-Cast Samples containing 7.98 per cent. Sb and 1.70 per cent. Ni.

A number of melts were made using sand free from coal dust to produce keel block castings with and without chills. In all cases no flux was used, the oil burner of the furnace being set to give slightly oxidising conditions. The effects of varying the casting temperature, adding a small amount of zinc and dispensing with the addition of nickel were studied, the details of the results obtained being given in Table X. It will be noted that generally the lower the casting temperature the higher the hardness and other mechanical properties. The addition of a small amount of zinc confers a slight improvement in properties, while the properties of the nickel free alloy are much inferior to those obtained on the nickel containing alloy.

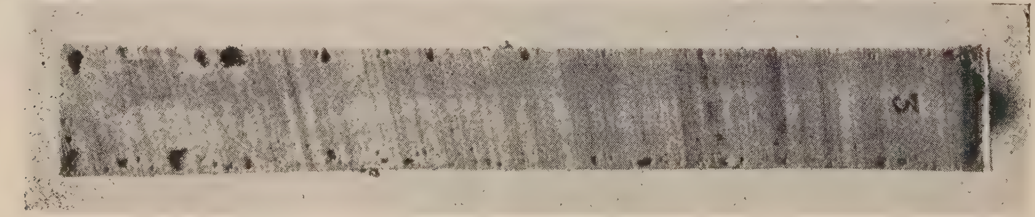

Fig. 19.—Gas Unsoundness in Sample of Cu-Sb-Ni Alloy cast in Sand containing Coal Dust (approx. ⅔).

In the sand cast condition the results are somewhat inferior to those claimed by the Hamilton Gear & Machine Company. Further work is required with a view to removing porosity in comparatively thick sand cast sections arising from the wide freezing range of approximately 400 deg. C. Also the tendency for the hard β phase on slow solidification to form rather continuous films around the dendrites is a factor contributing to the low strength values obtained in the comparatively heavy section of the keel block castings made entirely in sand.

The results show the advantages likely to be obtained by the use of chills on castings of heavy section.

THE ANALYSIS OF COPPER ALLOYS CONTAINING ANTIMONY AND NICKEL

By R. Woollen, B.Met.* (Associate Member)

In alloys of this type, where the copper may be the preponderating element, the well-known sulphide method is not satisfactory. However, a number of methods have been worked out which can be satisfactorily applied in these circumstances. Evans ("Analyst," 54, 395) has shown that antimony can be precipitated in the presence of copper by means of sodium hydrosulphite and Lassieur and Torrance ("Analyst," 62, 719) have shown that copper can be deposited from solutions containing antimonic fluoride ions. In addition to these methods, copper and antimony may be deposited together from chloride solutions using controlled cathode potential (Torrance, "Analyst," 62, 719), and subsequently separated as above. The choice of method used will depend upon the individual and availability of suitable apparatus.

Antimony

Weigh 1 grm. into 400 mls. tall beaker. Dissolve in a mixture of 15 mls. hydrochloric acid, 5 mls. nitric acid, and 20 mls. water. Add 10 grms. of citric acid (20 mls. of a 50 per cent. solution), and make the solution faintly alkaline with ammonia. Treat a saturated solution of potassium cyanide with bromine water until a drop removed gives no violet colour with sodium nitroprusside. Add this solution to the ammoniacal solution of the sample until the blue colour is just discharged, add 20 mls. in excess, followed by 50 mls. of a 20 per cent. solution of ammonium chloride and 7 grms. of sodium hydrosulphite. Heat to boiling and allow to stand on steam bath for 1 hr., add 2 grms. more hydrosulphite and place in running water to cool. Stir in a little paper pulp. Filter through a pulp filter and wash with a cold solution of 20 mls. saturated potassium cyanide, 4 grms. ammonium chloride, and 2 grms. sodium hydrosulphite in 400 mls. water. The filtration and washing should be carried out as quickly as possible to avoid oxidation and resolution of antimony. Boil the filtrate, ignore the presence of sulphur, but if it is blackened by the presence of antimony add more hydrosulphite, boil, cool and filter as before.

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* Messrs. Henry Wiggin & Company, Limited.

Transfer the filter back to original beaker. Cover with 1:1 hydrochloric acid containing bromine. Stir up the pulp and when the antimony is dissolved strain off the pulp, washing with 1:1 hydrochloric acid into a 400-ml. tall beaker. Add sulphurous acid a few mls. in excess of that required to discharge the bromine colour, and evaporate the solution down to 10 mls. (approx.). Add 10 mls. conc. hydrochloric acid, 100 mls. water, and heat to boiling. Add 2 or 3 drops of methyl orange (0.1 per cent.) and titrate at not less than 80 deg. C. with standard potassium bromate until the indicator colour is discharged. Considerable differences in the result occur according to the time of addition of the indicator. It is desirable to delay the addition until the last possible moment, say about 1 ml. from the known end point. Unless the antimony content is known the determination should be duplicated in order that this procedure may be adopted. (Potassium bromate, 2.782 grms. per litre. 1 ml. = 0.006088 grms. antimony.)

Copper

Dissolve 0.5 grm. in a mixture of 5 mls. conc. nitric acid, 5 mls. hydrofluoric acid and 10 mls. water. Boil off the oxides of nitrogen, dilute to 150 mls. Add a solution of potassium dichromate dropwise until the liquid is distinctly yellow and electrolyse at room temperature at 1 to 2 amps. for 1 hour.

If any considerable number of these determinations are required the beakers used should be segregated and retained for this purpose as they become perforated after a time.

Nickel

Dissolve 1 grm. in dilute nitric acid. Dilute to 150 mls., add several grms. tartaric acid, and make faintly alkaline with ammonia. Heat to 70 deg. C., and add an excess of dimethylglyoxime reagent. Filter and wash with hot water. Dissolve the precipitate back into the original beaker with hot dilute hydrochloric. Make alkaline and precipitate as before. Filter, wash and determine either by drying and weighing as complex or igniting and weighing as nickel oxide.

Copper and Antimony by Electrolysis

For the apparatus necessary and fuller details of these determinations, reference should be made to "Electrochemistry and Electrochemical Analysis," Vol. 11, by H. J. S. Sand. Dissolve 0.4 grm. in 400 mls. tall beaker by adding 10 mls. conc. hydrochloric acid, 10 mls. water and 2 or 3 *drops* conc. nitric acid. Torrance dissolves white metals in hydrochloric acid and potassium chlorate but the high copper alloys take overnight to dissolve in this way. The substitution of a small amount of nitric acid gives rapid solution and has not been observed to cause any trouble.

When the alloy is dissolved add 5 mls. conc. hydrochloric acid, dilute to 150 mls. and add 1 grm. hydrazine hydrochloride. The liquid is electrolysed with Fischer's electrodes at a P.D. saturated calomel electrode-cathode of 0.4 volt and at a temperature of 70 deg. C. Copper and antimony are deposited together and 30 minutes are required to remove the last trace of antimony. The electrolyte may be preserved for nickel, zinc, etc.

Dry and weigh the copper plus antimony deposit.

Dissolve the deposit from the electrode in a mixture of 5 mls. conc. nitric acid, 5 mls. hydrofluoric acid, and 10 mls. water. After boiling off the oxides of nitrogen, dilute, and after adding potassium dichromate until the solution is yellow, deposit the copper at room temperature with a current of 1 amp. for 1 hour. Dry and weigh the deposit.

The weight of antimony is obtained by difference.

Antimony results obtained by the two methods are given below:—

Sample No.	A.	B.	C.
	Per cent.	Per cent.	Per cent.
Electrolytic	8.30	7.15	7.98
Hydrosulphite	8.25	7.12	8.09

ESTIMATION OF ANTIMONY IN 90-8-2 COPPER-ANTIMONY-NICKEL ALLOYS

By JAMES MCPHEAT* (Associate Member)

To 1 grm. of sample add 0.2 grm. tin (C.P.) and dissolve in 25 mls. dilute nitric acid (1:1). When completely dissolved boil down to 10 mls. bulk and add 100 mls. boiling water. Allow to settle for half an hour, keeping the temperature just below boiling point. Filter in a small close filter pad and wash with boiling water. Discard filtrate.

Transfer the pulp and residue to a 350-mls. conical flask and add 15 mls. nitric acid (conc.), 5 grms. ammonium persulphate and 15 mls. sulphuric acid (conc.). Boil down to strong fumes of SO_3. If the solution is brown, repeat, using 10 mls. nitric acid (conc.) and 2 grms. ammonium persulphate.

When colourless, cool, add 100 mls. water, 20 mls. hydrochloric acid (conc.) and 3 grms. sodium sulphite. *Boil until absolutely free from* SO_2 (approximately ten minutes). Dilute to 200 mls. with water and cool to 10 to 15 deg. C. on ice. Titrate with potassium permanganate (standard solution), until a permanent pink.

Standard Potassium Permanganate.—2 grms. potassium permanganate per litre. Standardise against pure sodium oxalate or alternatively against pure antimony. 1 ml. potassium permanganate = 0.002 grm. antimony.

Notes

1.—In alloys containing an excess of tin, the antimony is precipitated quantitatively with the meta-stannic acid.

2.—If the solution becomes cool during the first filtration, some of the meta-stannic acid may dissolve.

3.—Ammonium persulphate and nitric acid are used to destroy the filter paper and to dissolve the tin plus antimony.

4.—If arsenic is present, correction must be made for the arsenic content.

This method for the determination of antimony is simple and accurate and does not call for a highly skilled operator. Copper and nickel can be estimated by the usual methods. The effect of other elements has been checked and the process has been tested out by three operators who had not tried it before. Very satisfactory results were obtained.

DISCUSSION

MR. F. HUDSON, Convenor of the Non-Ferrous Sub-Committee, who presented the Report, said the work done in this Report was started on behalf of the Admiralty, following information from Canada on the development of a new type of gear material containing 7 to 8 per cent. of antimony, 1.5 per cent. to 2.5 per cent. of nickel and the balance copper. It had been claimed that this alloy was considerably better than the ordinary tin bronzes for gear application, and the Admiralty felt that, if such was the case, it might be used in connection with the national effort. The intention of the Non-Ferrous Sub-Committee of the Technical Committee was therefore to make a Report to guide the

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* Messrs. G. & J. Weir & Company, Limited.

Admiralty in two directions, (1) giving production data and how the alloy would behave in the foundry, and (2) to give, if possible, some indication as to the value of the alloy in service. This Report primarily covered the first aspect of this work, *viz.*, the behaviour of the material in the foundry. A foreword had been added giving an indication of the available literature which had been published, and this mainly hinged round the constitutional diagram. Mr. Hudson then briefly summarised the general conclusions arrived at as set out in the Report.

In the course of further remarks, he said it had been hoped at this meeting to give some additional information as to the results of service tests, but in some cases these results had been delayed and all the data being collected were not yet available. However, he hoped that some of the investigators who had been engaged in this work might be able to say something following further tests that they might have made in their works. In conclusion, he thanked those who had collaborated in this work for their great assistance and for the willingness with which they had come forward in a very difficult time to conduct tests on this new material.

Wear Tests Unconvincing

Mr. J. Arnott said there were two questions which arose with regard to this new alloy. The first was as to how the alloy behaved in the foundry. It had been found that the alloy responded to known treatment. The first melt was slightly unsound, but an oxidising treatment of the usual type applied to the bronzes gave reasonable soundness. The tests were in the 10-ton region so far as tensile was concerned, but it had been possible to get 14 tons. Generally speaking, however, this was a 10-ton alloy in the average sand-cast condition. As to usefulness, his firm did not make gear bronzes, but they had many applications in which economy in tin might have been of use. They therefore submitted pieces of the material to friction tests on a wear-testing machine which they had used for something like 20 years, and the conclusion reached was that this material was not as suitable as a leaded bronze under the conditions they were familiar with, as set out in the Report. Possibly that was an unfair comparison, because this new material was non-leaded, and it had been found, without exception, that a leaded alloy, under equal conditions, was better than a non-leaded alloy. Apart from that, they had no way of assessing its value as a bearing bronze. However, the supply position was not so favourable as it might be, and it seemed that it would be as difficult to get antimony as tin. Therefore, on the whole, from his own angle, this material, as a substitute for the tin-bronzes, did not appear to warrant a change.

Oxidising Atmosphere Needed

Mr. E. J. L. Howard said that Mr. Brown and himself carried out these tests to ascertain the founding properties, and what value the alloy would have, apart from gears, in general engineering practice. The foundry investigation showed that the alloy was prone to gas absorption, and this took place in both virgin metal and in re-melted metal. It could, however, be largely overcome by suitable melting conditions, *i.e.*, to melt in a strongly oxidising atmosphere, and reduce with phosphor-copper prior to pouring, and casting at the correct temperature, which seemed to lie between 1,100 and 1,200 deg. C., depending on the nature of the castings. It was noticed that a very definite change took place in the metal at about 1,100 deg. C. It became heavily crusted, and this had to be broken away before pouring could take place. The metal was then very fluid and ran well, and there seemed no reason at all why normal bronze founding methods should not be adopted. The physical properties of the metal seemed to be rather lower than in the case of materials usually employed for gears which called for a minimum of 14 tons, an elongation of 7 per cent., and a Brinell hardness of 69. The casting temperature did not affect to any marked degree the ultimate tensile, the yield point, elongation or Izod figures, but, of course, it affected the hardness. (Mr. Howard then summarised the section of the Report "Tin-free Gear Bronzes" contributed by himself and Mr. Brown.)

The other investigators also briefly introduced their sections of the Report. In the course of his introductory remarks, Mr. A. Dunlop also referred to the results obtained in corrosion tests with this alloy in his laboratory. It could be concluded from these tests that: (1) On the basis of the loss in weight in immersion tests under laboratory conditions, followed by chemical cleaning, the Sb-Ni-Cu alloys appeared somewhat less resistant to corrosion than tin-bronze. Except in stagnant sea water, the corrosion resistance was increased by the addition of zinc. (2) In aerated or stagnant tap water, or stagnant sea water, in the absence of abrasion, the Sb-bearing alloys would be expected satisfactorily to replace tin-bronze, but in freely-aerated sea water the loss in weight would be greater. (3) The Sb-containing alloys owe their corrosion resistance largely to semi-protective films, which are not as resistant to abrasion as those formed by tin-bronze. The alloys might not, therefore, be satisfactory where corrosion and abrasion occur together.

Discussion of Report

Mr. C. Coldron Smith (E.-in.-C. Dept., Admiralty) expressed the view that the Report, with its seven contributions, illustrated a method of attack on a problem which might more often be followed in investigations of this kind because of the rapidity in obtaining reliable results. The Report was noteworthy in that the different contributions were in general agreement with one another. In the editing of Dr. Walpole's contribution he thought that there was an oversight in not relating it to the thermal equilibrium diagram which Dr. Walpole must have had in mind and which was presumably the Hansen diagram shown in Fig. 1.

He disliked the use of the word "phase" as applied to the micro-constituents of these cast alloys, which were obviously not in thermal equilibrium. The words "constituent" or "micro-constituent" were preferable. Apart from these small points he would have liked to have heard from those who did the foundry work what melting loss occurred with the antimony. He assumed that it must have been small, otherwise attention would have been drawn to it. In view of the rather poisonous nature of antimony vapour and of its oxides, perhaps a word of warning might not be out of place.

The wear tests mentioned by Mr. Arnott were of exceptional interest in view of Mr. Arnott's long experience with this method of testing, but it was not stated whether these tests were carried out with the alloy in the aged condition or in the as-cast condition. There was one aspect of the wear problem that would have to be looked into, and that was the corrodibility of the alloy on exposure to hot oil and air. Many people knew that some successful attempts had been made to arrange the various bearing alloys in an order of merit in regard to corrodibility under these conditions. The behaviour of copper-nickel antimony alloys in comparison with the tin bronzes would need to be ascertained by some such corrosion test.

Blowhole Formation

Mr. W. A. Baker, B.Sc., said it was striking that all the investigators agreed that the physical properties of the material were rather poor in the sand-cast condition. Although the Report indicated that chilling of centrifugal casting gave substantially better results it followed that the new material suffered from a serious limitation in its application. In the introduction to the Report there was an implication that the main interest in this material was as a substitute for gunmetal, emphasis being laid on the absence of tin from the alloy. That was a point upon which he would like to comment. In a previous report of the sub-committee on low tin and tin-free bronzes it was considered that silicon bronzes did not offer very much promise as a substitute, one reason put forward being the high copper content. That, of course, applied equally to this antimony alloy. It was gathered from what had been said by another speaker that antimony was also in short supply, which obviously made the position somewhat worse.

Continuing, Mr. Baker said his main purpose in speaking was to give the results of a few tests carried out by the British Non-Ferrous Research Association at Mr. Hudson's instigation. Some tests were carried out to determine the cause of the porosity encountered by various investigators, as stated in the Report, and he was given to understand that the porosity occurred in the foundry when the metal was melted under reducing conditions, and particularly when the melting temperature was high. There was also a suggestion that the presence of coal dust in the moulding sand was a contributory cause. Only a few tests were made by the B.N.F.M.R.A., but the results confirmed the general finding that an oxidising atmosphere yielded castings free from gas porosity, and that a reducing atmosphere, particularly when the metal was overheated, introduced considerable quantities of gas. However, in these tests the castings did not contain any of the sub-surface blowholes mentioned in the Report. The porosity was very widely dispersed, and there were very small cavities not visible to the naked eye, but visible under a microscope. The matter was pursued further in an attempt to produce large blowholes. It had been suggested that carbon monoxide was a possible source of these blowholes, the reason being that in an earlier investigation it had been found that a material subject to carbon monoxide gas unsoundness sometimes evolved gas very freely early in freezing, and gave large blowholes near the surface. To check this, the antimony alloy was melted in a high frequency furnace in an atmosphere of air, and under these oxidising conditions sound castings were obtained. Then the charge was covered with charcoal and allowed to stand, and at intervals further small castings were poured. As the holding time under the charcoal increased small dispersed cavities first appeared, and later the large sub-surface blowholes mentioned in the Report were obtained. When the charcoal cover was removed and castings were poured at intervals, the melt passed through the opposite cycle. The large blowholes disappeared, leaving smaller cavities visible only under the microscope. Finally, when the material was thoroughly oxidised it was substantially free from gas porosity. These results were by no means conclusive, but, in his view, they suggested that carbon monoxide was a possible cause of this trouble. In any case, it was clear that contact with charcoal should be avoided as far as possible.

Effect of Coal Dust in Sand

A further test was made to try and confirm the suggestion that coal dust in the sand caused the trouble. Moulds were made from Mansfield sand, some being covered with a black wash, and material melted in an oxidising atmosphere was poured into them, but no porosity was observed. Thus, his observations were not quite in line with the suggestion in the paper that carbon in the mould was the source of the trouble.

A few tests on the corrosion resistance of this material were made, and again he emphasised that only a very few tests were made and that the results were only indicative. Two types of test were carried out. In one case, samples were exposed to corrosion under impingement conditions in sea water, and in the other case they were exposed to static immersion in sea water. In each case the antimony-nickel bronze was compared with 88:10:2 gunmetal, and an 86:7:5:2 alloy. Under impingement conditions, (*i.e.*, sea water moving at 15 ft. per sec. and carrying 3 per cent. entangled air), the antimony alloy showed serious attack in only 8 days. There was considerable shallow pitting at the point of impingement and a considerable etching of the material and from the B.N.F.M.R.A.'s experience of other non-ferrous metals of proved behaviour, and from the check tests on the two gunmetals, it seemed fairly certain that the antimony bronze would fail rapidly under impingement conditions. The two gunmetals were run for 14 days, and still showed little signs of attack. Under static immersion conditions, the antimony bronze was substantially similar to the tin-bronzes. Although the differences were very slight, the antimony bronze, if anything, was the most resistant of the three and the 86:7:5:2 was the least resistant of the three.

Coal Dust in Moulds for N.F. Castings

MR. A. DUNLOP (one of the investigators), referring to the point made by Mr. Baker as to the effect of carbonaceous material in the mould, said that the tests he had been responsible for were with moulding sand containing 3 to 4 per cent. of coal dust—not just a dressing. The castings poured into the moulds were comparatively massive, so that the sand was pretty well heated all over and gas was liberated before the alloy completely solidified. In all his tests the metal was melted under oxidising conditions and the results were obtained with a heavy casting, say of 2- to 3-in. section and 8 in. long. In the case of castings without chills, there was "spewing," but excess metal poured into an iron ingot-mould sunk well. Successful casting had been carried out with coal dust in the sand, with castings of $\frac{1}{2}$- to 1-in. dia.

In reply to a comment by Mr. Dunlop, MR. BAKER remarked that he should have amplified his previous remarks. His casting was 2 in. dia. and 2 in. high, and the rate of cooling was not very fast. One of the points which he noted in reading the Paper was that the blowhole porosity was observed in castings made in sand containing coal dust, but the fact that no porosity was observed when separate melts were cast into other moulds was not quite so convincing as it might be. He suggested that the same metal should have been poured into sand moulds with and without coal dust.

MR. DUNLOP said it was the same melt.

MR. BAKER said that was not indicated in the Paper, and it should be made clear. If he remembered rightly, no further trouble was experienced when the coal dust was eliminated. However, Mr. Dunlop and himself had one point in common, and that was that the presence of carbon was undesirable.

MR. W. J. PYM, referring to the use of coal dust, said his firm had been specialising in bronze for some years and had never used coal dust. They hoped they had solved the problem by using wheaten flour mixed with the sand. They made high-pressure castings and had brought down the amount of scrap to less than 0.01 per cent.

Wear Tests

MR. P. T. HOLLIGAN, speaking of wear tests, said he appreciated that there had not been very much time for service tests. Mr. Arnott mentioned tests in which the material had been run against similar material and also against phosphor bronze. What results, if any, had been obtained when running the copper-antimony-nickel alloy against soft and hard steel respectively? Mr. Arnott had mentioned hard steel, but had anything been done with soft steel, lubricated and unlubricated?

Mr. Arnott replied that in the majority of gear applications, moderately hard steel was used, but he could not answer Mr. Holligan's question because he had not been concerned with gear applications.

Mr. Peake, also speaking with regard to wear tests, said he understood there were still one or two tests outstanding, but the great point of interest to him was whether this alloy would give exceptional wear resistance for gearwheels, worms, etc. Was it to be taken that at some subsequent date, when further tests had been completed, that the members of the Institute would be informed?

The **Chairman** (Mr. D. H. Wood, Senior Vice-President), said that the results of further tests would be published probably with this Report together with the discussion upon it. (See page 37.)

Mr. Hudson, in a brief general reply to the discussion, took Mr. Coldron-Smith's point as to loss of antimony in melting, and said he did not think there was much loss and he did not think there was much fear of poisonous fumes being given off, although not quite enough was known about that point yet. Mr. Arnott's wear tests were carried out with the alloy in the as-cast condition, and not heat-treated. He agreed with Mr. Coldron-Smith as to the desirability of assessing the corrodibility of this alloy in oil, and much more work might be done in that direction. So far, however, none had been done. He thanked Mr. Baker for his very interesting, collaborative, and constructive remarks and added that the sub-committee was much indebted to the British Non-Ferrous Metals Research Association for their assistance. The results of the outstanding service tests would be made known, as the Chairman had said. At the moment there were several outstanding tests. For example, Messrs. Holroyd were conducting actual tests on gears, and the results should clear up the question of service properties of this alloy. The main issue was that if this new alloy did not show a considerable superiority as a gear material over the existing tin-bronzes, in view of the supply position the sub-committee felt that no change was warranted. Everything hinged on the actual service results obtained, and these would definitely be published with the discussion and Paper later on.

Vote of Thanks

Mr. L. G. Beresford, proposing a vote of thanks to the authors of the various Papers contained in the Report, said this was one of the finest examples of international co-operation. It had started with a Canadian firm, who handed on their results to British foundrymen and the sub-committee had made a very good job of the work they had undertaken.

Mr. Holligan, in seconding, asked whether there was available any information as to the experience of the Hamilton Gear Company with gears made of this material. The vote of thanks was cordially given.

Mr. Hudson said that a copy of this Report was to be sent to Canada with a covering letter asking for the information Mr. Holligan had mentioned.

WRITTEN ADDENDUM

Mr. E. J. L. Howard later wrote that tests had been made to ascertain the effect of running sleeves and bushes made of copper-antimony-nickel alloy with water lubrication under a heavy load. For the purpose of the test a sleeve was mounted on a shaft and rotated at 1,500 revs. per min. A stationary loaded bush was located around the sleeve with a diametral clearance of 12 mils between the two. The weight of the bush and its mountings was 91 lbs. plus an additional load of 400 lbs., making the total of 491 lbs. Undue wear was indicated by the power to drive fluctuating from relatively low values to high values, measured with an ammeter. The results obtained were as follows:—

Sleeve material.	Bush material.	Brinell hardness.		Result 491 lbs. load.	Ammeter reading.
		Sleeve.	Bush.		
Copper-nickel-antimony	Copper-nickel-antimony ..	76	76	Seized	5—15
Leaded phosphor bronze	Ditto	58	73	Good	1—2
Phosphor bronze ..	Ditto	64	72	Fair	2—10

These tests indicate the metal would run with phosphor bronze or a leaded phosphor bronze without any tendency to seize. The tests made with the sleeve and bush of the copper-antimony-nickel alloy showed seizure to occur.

Some corrosion tests were also conducted under static conditions at room temperatures against weak acids, sea water and acid salts. These indicate that taken all round the alloy is equal to phosphor bronze and leaded phosphor bronze of the following composition:—

	Phosphor bronze.	Leaded phosphor bronze.
	Per cent.	Per cent.
Copper	92.0	84.0
Tin	7.5	7.5
Phosphorus	0.5	0.5
Lead	Nil	8.0

It was noted that the Hamilton Gear Company claimed higher physical properties than had been obtained here, and that no advantage was obtained by chilling. This did not agree with their experience.

The method of making this alloy suggested by Mr. Hyslop and Mr. R. F. Hudson, by having a small amount of zinc present in the charge, was quite good and certainly did tend to overcome the troubles due to gassing.

He did not follow Mr. Dunlop and Mr. Frank Hudson's claim that the gassing might be due to coal dust in the moulding sand. It might contribute to the defect, but he felt sure the root of the trouble was in the melting of the alloy and casting temperature, and that by the adoption of the correct procedure it might be overcome.

Mr. F. Hudson, in reply, wrote that the running tests, outlined by Mr. Howard, on the copper-antimony-nickel alloy under water lubrication were of considerable interest, and would be extremely useful as a guide to the behaviour of the alloy under particular service conditions. In regard to the question of gassing, there was no doubt that the main cause of this trouble would, in the first place, be due to the use of improper melting methods. It seemed evident, however, that if gassing of the copper-antimony-nickel alloy persisted even under correct melting conditions, then the cause of the trouble might be the presence of coal dust in the moulding sand. The effect of coal dust in this direction would, of course, be greater than a relatively inert carbonaceous material, which might be used as a mould facing, such as blacking or plumbago.

Service tests conducted by Messrs. Rolls-Royce, Limited, on 2¼ in. dia. magneto drive skew gears machined from a sand cast bar of copper-antimony-nickel alloy were not too satisfactory. Examination of the gears after test showed that they did not stand up as well as centrifugally cast phosphor bronze. A report was received that the gear teeth showed more signs of pitting and scuffing, as shown in Fig. 20, than was normally experienced. On the driving side four teeth, displaced 90 degrees from each other, showed moderate pitting. On the non-driving side two teeth showed very light plucking. The bedding was rather broad, and there was also an increase in backlash of 7 or 8 thousandths of an inch after testing. Repeat tests using gears machined from chill, instead of sand cast stick were also found to be less satisfactory than gears made in centrifugally cast phosphor bronze.

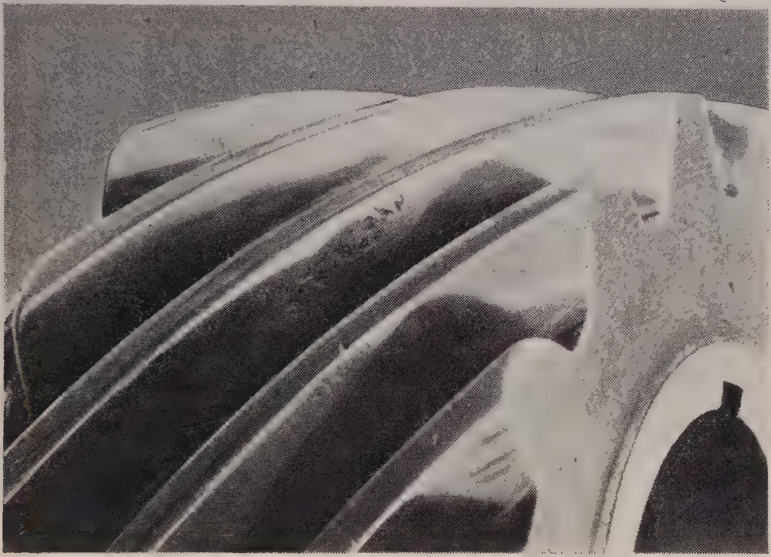

FIG. 20.

Tests were also carried out by Messrs. John Holroyd & Company, Limited, using the copper-antimony-nickel alloy in the chill cast condition in comparison with centrifugally cast phosphor bronze. The procedure was to run each of the bronze materials in turn with a 3 per cent. nickel case-hardened steel blank under conditions of speed and relative motion which correspond to the conditions that occur in a worm and wheel in practice. In both cases the load was increased at intervals until failure took place. Briefly stated, the results obtained was as follows:—

(1) The centrifugally cast phosphor bronze failed by pitting after running nearly a million cycles, and under a final compressive stress of 49.6 tons per sq. in.

(2) The chill cast copper-antimony-nickel alloy failed by pitting at rather less than half a million cycles, and under a comprehensive stress at the surface of about 39 tons per sq. in.

The co-efficient of friction of the copper-antimony-nickel alloy was about 8 per cent. higher than that of the phosphor bronze at all sliding velocities up to 3,500 ft. per min. The lubricant used was a castor base worm gear oil and the temperature was maintained at about 60 deg. C. throughout the whole series of tests.

It would appear from the foregoing that the copper-antimony-nickel alloy is certainly no better, and probably not quite so good as existing materials for use as gears.

Paper No. 769

A Method of Correlating Foundry Practice and Quality of Light Alloy Castings

By H. G. WARRINGTON* (Member)

I—INTRODUCTION

Many interesting Papers have been presented on foundry control, and many others describe the moulding methods that have been evolved to overcome the difficulties encountered in making a particularly troublesome casting. In a modern foundry laid out for mass production of light alloy aero-engine castings a preliminary investigation of the methods to be employed is essential, in order that satisfactory castings are produced with the minimum of wasters. In a jobbing foundry this is more than ever essential, where the number of patterns in use is greater per unit of floor area, and the possibility of small numbers off a greater variety of types means that the time that can be spent experimenting with moulding methods must be cut to a minimum.

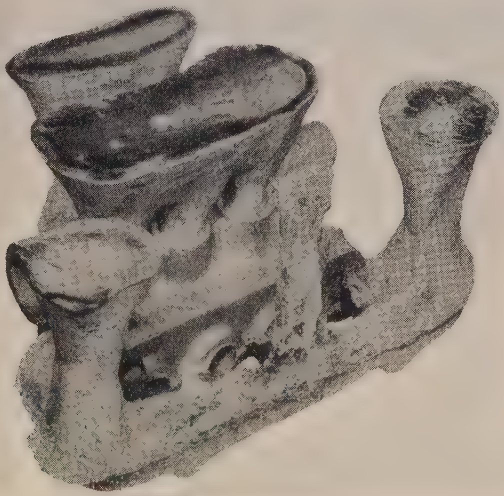

Fig. 1.—No. 3573.

In a foundry, moreover, that is closely associated with alloy developments, castings are often required for prototype engines and aircraft, perhaps only two or three off in a desperate hurry. They may be forgotten for perhaps six months, and then after tests are completed, not only are production orders received, but are divided amongst two or three other foundries in the country who require ingot material of the alloy originally specified, and welcome some assistance as to the moulding methods that will get the job under way as quickly as possible. It is incumbent on the supplier of ingots to specification to be in a position to recommend casting practice and to be able to take on any job at a moment's notice.

With this problem to face it is evident, first, that a routine must be established for recording moulding methods so that a casting can be picked up again after a lapse of time, and recommendations made in a clear manner to other foundries, and, secondly, that a rapid means of examination is conducted, and what is more important that the results of the examination are transmitted to the foundry in the case of an unsuccessful first attempt so that the correct modifications can be adopted to produce a sound casting next time.

Following-up in Production

A third factor which must on no account be overlooked is the importance of checking the production run as well as the first few samples. The early castings are usually produced under the eye of the foreman moulder, the metal temperature check, fluxing, degassing and grain refining if called for, conducted by a laboratory worker, and the heat-treatment given special priority. Under these conditions a perfect casting can be produced by a method that is not flexible enough for later production, and it is obviously more practicable to provide a foolproof method than to tighten down on detail to the extent that one is always working near the danger line.

Similarly a further examination is required in detail with a follow-up in the case of any change in procedure that may be necessitated in the course of production. An example may be given of the results of changing an aero-engine cylinder head from floor to machine moulding. The machine method meant elimination of sprigs between the fins, and the substitution of oil-bonded silica sand for natural bonding sand. Otherwise the methods were identical, but sections cut through the machine-moulded castings demonstrated that a hot spot had developed exactly opposite the runner gate, causing a shrinkage cavity, which was just hidden from superficial inspection by a skin of sound metal. Observation showed that the solidification period with the altered sand was considerably longer, with the result that whilst risering was still adequate a new method of gating had to be developed before machine moulding could proceed.

The accumulated knowledge of these recorded effects of various moulding methods can lead to later changes in production, even if proceeding satisfactorily, as reflection on the first examination and the later follow-up may frequently indicate where a change can be introduced, not necessarily to improve the quality of the castings, which was the initial object, but to reduce the man-hours employed in moulding, coremaking or fettling. Such modifications, however, on aircraft castings subject to radiological examination and usually highly stressed are of necessity a secondary consideration, and the first object must always be to obtain a sound and uniform component.

II.—EXAMINATION OF "FIRST OFF" CASTINGS

The first casting made is invariably used for dimensional check, and in all foundries there is, or should be, well established machinery for transmitting this information to the pattern shop, initiating modifications and recording departures from drawing. Slight variations from dimensional tolerances do not often affect the moulding methods, however, and for the control system described it is convenient to make two castings from the first pour, the second one being sent to the laboratory for control check. The completeness of this investigation will depend on a number of factors, such as the size and intricacy, design stressing, number required, and previous experience on similar types of casting in the alloy employed.

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* Production Metallurgist, High Duty Alloys, Limited, Slough. The Author was awarded a Diploma for this Paper.

A full investigation will seldom be necessary, and indeed as a routine check, to be conducted with the precision of check tensile testing or dimensional inspection, its main advantage would be lost if too much time were employed getting down to unnecessary detail which might delay getting important features back to the foundry in time to control the first production run. The examples given later, therefore, whilst showing certain features in common, will vary in the method of evaluation, particularly on first check, with the importance of the casting.

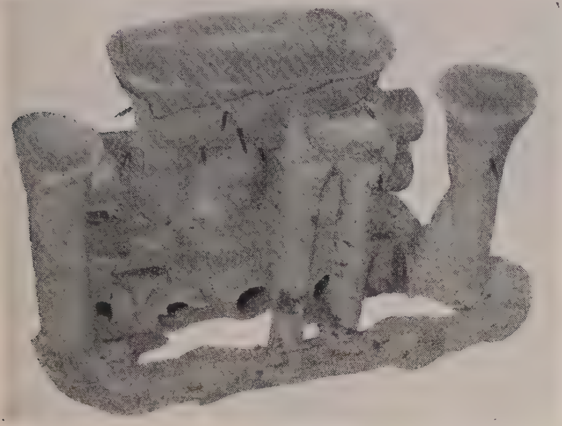
FIG. 2.—No. 3652.

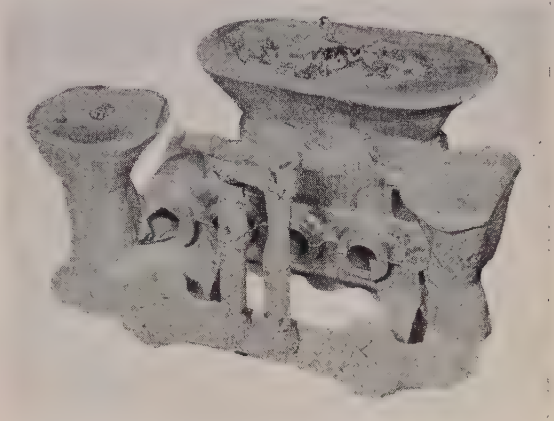
FIG. 3.—No. 3653.

Photographic Records

The essential feature of all reports is the record of the method of moulding employed, and it was decided that the first and most important record must therefore be a clear photograph taken in studio lighting of the casting complete with runners and risers. This must be supplemented by a list of dimensional details of the runners, gates, risers, etc., the moulding and core sand employed, and the casting temperature. The visual appearance of the casting must be described in all cases, but the remainder of the examination will vary with expediency. To locate internal shrinkage, porosity, grain size variations and segregation, use may be made of radiography, polished and etched sections, fracturing and pressure tests.

To evaluate stress requirements and general homogeneity, tensile test-pieces may be taken from a number of locations, and in the case of large piston castings a Brinell hardness survey is taken on all machined surfaces. These can be itemised as follows:—(1) "First off" castings, one to dimensional check, one to quality check; (2) photograph showing runners and risers; (3) record of dimensions of runners and risers; (4) details of moulding sand, core sand, pouring temperature, etc.; (5) visual examination; (6) radiological examination; (7) heat treat, if required; (8) fracture examination (essential for heat-treated magnesium-base alloys); (9) macro and micro examination of typical sections, face polished and etched; (10) tensile tests from representative sections (stressed castings); (11) Brinell hardness survey (piston castings); (12) pressure test (after machining if possible); (13) analysis check for composition variations.

The completion of an investigation of this nature

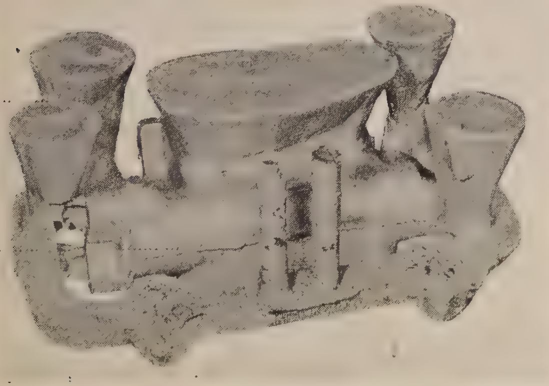
FIG. 4.—No. 3654.

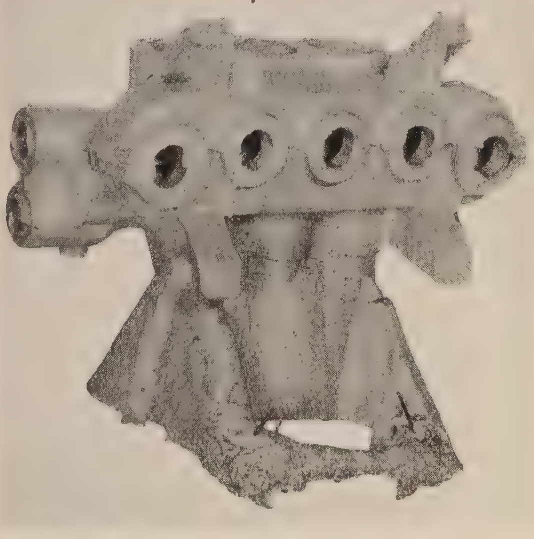
FIG. 5.—No. 3662.

would delay castings urgently required, and sufficient information to enable the foundry to proceed can normally be given after radiological examination has been completed. This is achieved by means of an interim memorandum sent from the laboratory to the foundry superintendent approving the method for production or notifying the necessity for modifications, with descriptions of the defects encountered. In this way the necessity for an individual report for each modification is unnecessary, the investigation being held over until another casting is available, so that the official record will normally describe the satisfactory method, and finish with the formal approval for production.

On many simple components it is simply necessary to report that "the casting has been photographed, examined visually, radiographed and fractured. No defects were noted and the method is approved for production." This assumes, of course, that it is of a type that has a good previous history, and that from knowledge of similar components in production the examiner is confident that no difficulties such as distortion or cracking will occur during heat-treatment, and that from his knowledge of the alloy concerned and of the customers' requirements that there will be no doubt that the required mechanical properties will be achieved. This is no mere assumption, and links up the "first off" examination with another type of investigation that is conducted from time to time.

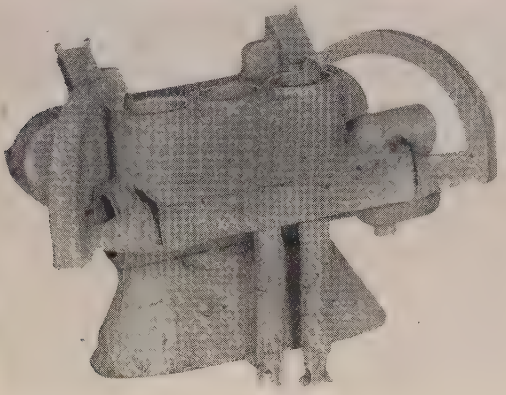

FIG. 6.—No. 3801.

When a new type of alloy is introduced into the foundry, before production castings are made, an assortment of typical patterns are chosen, whose reactions to standard alloys by established moulding methods are known, and a few castings of each are made. If these are successful, or achieve success after modifications to suit the new material, it is then known that for certain general types of moulding castings will be expected to have certain mechanical properties.

III—SUBMISSION OF CASTINGS

The mechanism by which the casting is submitted for examination may be varied to suit local conditions. It may be established that when the dimensional check is made, the inspection department require two castings, only one of which is to be fettled, and the other they will record after a rapid visual survey and pass on to the laboratory for the major investigation. This will ensure that obvious defects such as draws, cold shuts or crushes are not submitted, but has the disadvantage of breaking the contact between laboratory and foundry.

Another method is for the laboratory man who is responsible for quality control in the foundry to have access to the production department's list of requirements for new castings, and arrange to be present once or twice during the moulding, and, when the casting is poured, noting all relevant details. He can then discuss the moulding and the apparent results on the spot, and take the casting away for testing. A cast-iron ruling should not be made on this point, however, as on a number of new jobs a glance at the pattern will indicate that the examination will merely be a formality and that production can go straight ahead from the moment it is received in the foundry, the inspection department merely making sure that nothing is despatched to the customer until the result of the examination is known.

It is obviously important that this decision must

SUBMITTAL NOTE FORM

SAMPLE TO LABORATORY FOR INVESTIGATION

All Samples to be sent to Laboratory Stores.

No. ....

Will you please investigate and report on the following material :

Customer ....
Component ....
Part No. ....
Alloy ....
Melt No. ....
Reason for submission ....
No. involved in complaint..............
Reference letter dated ....

gned .... Dated............

The above details to be filled in by Department submitting material.

No. ......

To : Mr.......................
From : Mr. A.

Will you please examine and report on the above samples, the investigation to include :

Chemical Analysis.
Microscopical Examination.
Macro Examination.
Grain Flow.
Brinell Hardness
Corrosion.
X-ray Examination.
Fracture.
Approval for Production.

Investigation completed :
....

TIME BOOKED
Name ....
Hours ....
Draft Received ....
Passed to Typists ....
Received from Typists .....

Please delete investigation not required.

Report No. ....

To Mr. B. No. ......
From : Mr. A.

Will you please progress this work which has been passed to Mr. ....

CUSTOMER COMPONENT

Sample Received by Laboratory Nos......... No. ......
For information please ring Mr. B. Phone *xyz*.

Signed ....
Date ....

THIS PORTION TO BE RETURNED TO DEPARTMENT SUBMITTING MATERIAL.

be taken wherever possible, not only to avoid the development of an irksome system for stopping good men working, but to develop a spirit of collaboration between the laboratory man and the foundry, and to allow the foremen and technical people freedom from an insistence on a routine to put their mutual efforts into consideration of the more difficult jobs where a cautious approach is necessary if valuable man-hours are not to be wasted moulding up for production of expensive scrap.

Progressing and Records

An important formality, however, that was found to be very necessary is the recording and progressing of each examination by means of a "Submittal Note," a copy of which is shown. There are several items printed on this form irrelevant to the examination of castings, so that it can be used as a universal record for submission of forgings, sections, sheet, etc., from production or customers' complaints or requests for special tests. The form is divided into three parts, one being kept by the department submitting the job, one containing the instructions in the case of special types of investigation, which accompanies the job to the laboratory and is attached to the manuscript of the report, and one which is filed in the laboratory administrative offices.

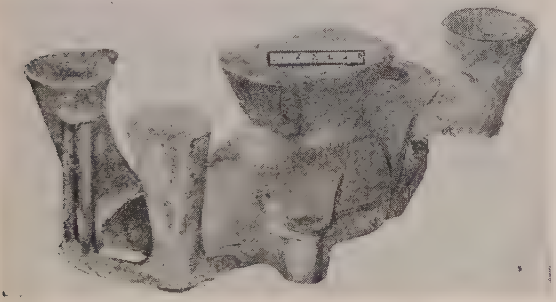

FIG. 7.—No. 3462.

Each part, separated by perforations, is printed with the same serial number for correlation and reference. The form then ensures that there is no doubt, when a casting has been submitted from the foundry, that the volume of work and time taken on the investigations are available, and that an unreasonable delay does not occur between submission and report without some inquiry being made. Each report is also given a serial number, and the method of casting is identified by this number in all works' correspondence. It is obviously simpler to refer to "method No. 2569," for example, than to say, "the method used for machine moulded cylinder heads, Part No. —, prior to our latest modification, and also avoids any possibility of error.

Copies of the reports are issued to the foundry, the inspection department and the management, and filed in the laboratory. A list of titles and references is circulated generally to all others who are likely to be interested and who can obtain copies on demand.

IV—TYPICAL INVESTIGATIONS

Example 1

The first example chosen is of a magnesium alloy casting which involved particularly stringent pressure test requirements, and owing to the amount of machining to be an almost perfect casting. A large number of attempts were made before successful castings were produced with low rejections, but a certain amount of production was carried on during the experimental series.

A Report on the Examination of a Number of Sand Castings to Part No. — for Messrs. —— in M.A. 181 to Specification DTD.59A

General.—Castings from several different methods of manufacture were submitted for laboratory examination and approval of the best method of manufacture and foundry technique. The castings were examined visually, photographed, heat-treated, radiographed and fractured for examination. The various methods of manufacture are illustrated by the attached photographs, Figs. 1-6. Below is a summary of the observations made upon examination of the castings.

Fig. 1.—Several castings were made by the method illustrated, but each succeeding casting incorporated slight modifications to the previous sample. In the first sample examined, several areas of shrinkage were apparent, particularly in the thick wall of the tube beneath the top riser and also in front of the riser at the back of the casting. This riser was omitted from all further castings without affecting the condition of the castings in general. In an attempt to overcome the shrinkage beneath the top riser, chills were placed in the cores, but the defect was only displaced and not eliminated. Further samples were made in which the top riser was given an asbestos liner. This is illustrated by Fig. 2, which is a photograph of a casting without the back riser.

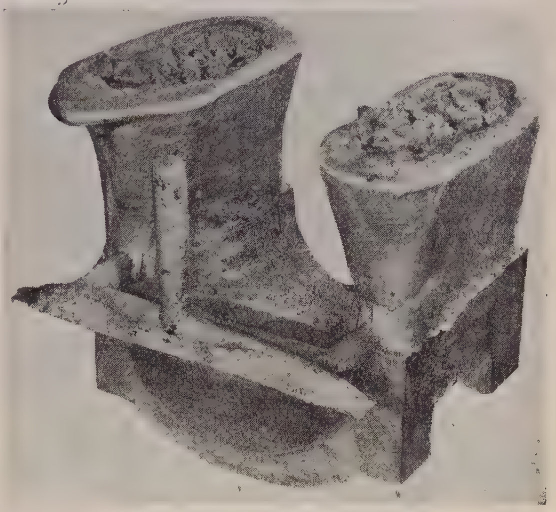

FIG. 8.—No. 3450.

Fig. 3.—In an attempt to eliminate the shrinkage beneath the bosses observed in previous castings, the casting was inverted, all details of running remaining the same as before. This modification produced little change in the severity of the defect in the affected area, whilst a further region of shrinkage developed in the bosses beneath the top riser. This modification was abandoned.

Fig. 4.—Another sample was made using the same running system as before, with the provision of additional gates, in an attempt to fill the mould more quickly and allow the top riser to function properly. Some improvement was evident, but the casting was still below a satisfactory standard for production to proceed.

Fig. 5.—At the risk of excessive turbulence in the mould, it was decided to "top run" the casting, the runner being gated into the top riser. An open top mould was employed, whilst steel wool filters were used in an attempt to check the flow of metal and minimise dross inclusions. Samples with one, two and three gates to the riser were produced, the most satisfactory results being obtained from the double-gated casting, which is illustrated by Fig. 5. A few production castings were made, but numerous rejections occurred due to dross inclusions.

Fig. 6.—The practice of "top running" the casting was discontinued and further samples submitted for examination in which horn gates to the bottom of the casting were employed, together with a large top riser. The gates were situated at the lugs in one sample, and at the end of the walls of the cylindrical bosses in the other. The latter sample gave the more satisfactory results of the two, and is illustrated by Fig. 6. Rejections on pressure testing of castings made by this method have not exceeded 2 per cent.

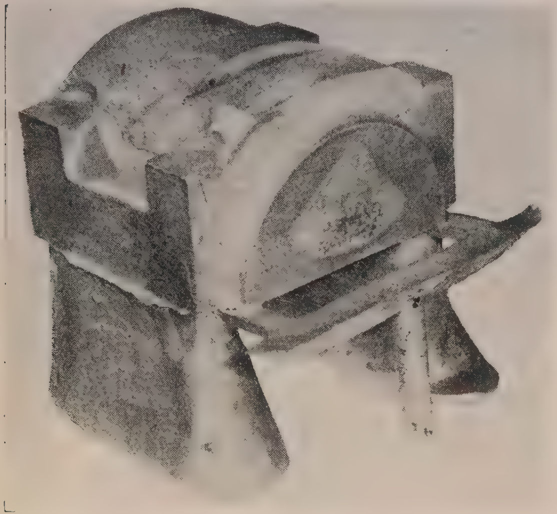

FIG. 9.—NO. 3450.

Conclusion.—Castings to this part number may be regarded as satisfactory for production to proceed using the method illustrated by Fig. 6. *Dimensional Details*:—(1) Downright, $\frac{7}{8}$ in. dia.; (2) channel, $1\frac{1}{8}$ in. by $1\frac{3}{8}$ in.; (3) horn gates, $\frac{7}{8}$ in., tapering to $\frac{5}{8}$ in. sq.; (4) riser, 9 in. by $5\frac{1}{2}$ in. top, $1\frac{5}{8}$ in. by 6 in. base, $3\frac{1}{4}$ in. high. The mould was made in Bedford silica sand plus ammonium bifluoride inhibitor, and the cores in Bedford silica sand bonded with Crulin B plus ammonium bifluoride inhibitor.

Example 2

The next example is a series of three reports, the first of which deals with the prototype of two patterns, and the two following being modifications found necessary on each casting as experience was gained in production.

Report on the Examination of Two Castings for —— Part Nos. 76204 *and* 76194 *to Specification DTD.*298

General.—These castings were submitted for examination for the approval of the method of manufacture. They were examined visually and radiographically.

Method of Manufacture.—Component 76204 is illustrated in Fig. 7 and 76194 in Figs. 8 and 9. Dimensional details are attached. The patterns were moulded in Mansfield sand and cores were of Southport plus Crulin B. The metal was cast at 710 deg. C.

Visual Examination.—The large casting, Fig. 7, appeared to be free from defect, but on the smaller component (Figs. 8 and 9) slight shrinkage defects were noted at X and beneath the riser on the inner surface of the casting.

Radiographic Examination.—No defects were apparent from the radiographs of either of the castings.

Conclusion.—The method of manufacture used for casting Part No. 76204 is considered to be satisfactory. The smaller component, although not possessing serious defects, may be improved by the application of chills to the porous areas and by improving the shape of the top risers to provide a more adequate feed.

Dimensional Details.—Part Number 76204: (1) Downright, 9 in. by $\frac{3}{4}$ in. dia.; (2) runner, $1\frac{1}{2}$ in. by $1\frac{1}{4}$ in.; (3) feeder, 11 in. height by 5 in. dia. top, 3 in. dia. base; (4) riser, 8 in. height by 7 in. dia. top, 5 in. dia. base; (5) gate, $7\frac{1}{2}$ in. by $1\frac{3}{4}$ in.; (6) riser, $5\frac{1}{2}$ in. height by 12 in. by $6\frac{1}{2}$ in. top, 9 in. by $3\frac{1}{2}$ in. base. Weights as cast, 161 lbs. *Part No.* 76194: (1) Downright, $4\frac{1}{2}$ in. height by $\frac{3}{4}$ in. dia.; (2) runner, 1 in. by $\frac{7}{8}$ in.; (3) gate, $\frac{7}{8}$ in. by $\frac{5}{8}$ in.; (4) riser, $4\frac{1}{2}$ in. height by $8\frac{1}{2}$ in. by $3\frac{1}{2}$ in. top, 7 in. by 2 in. base. Weight as cast, 43 lbs.; weight fettled, 23 lbs.

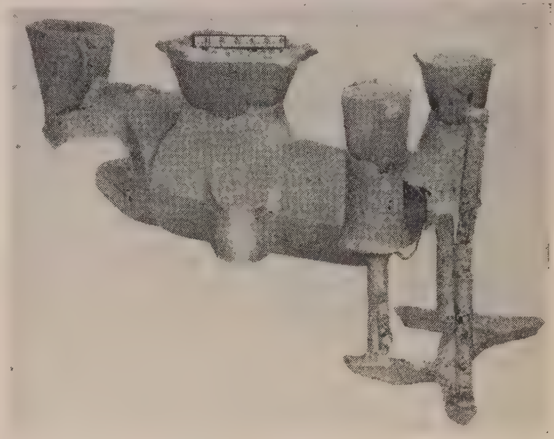

FIG. 10.—NO. 3499.

Report on the Examination of a Sand Casting for —— Part, No. 7620/4, *to Specification DTD.*298 *Made by a Modified Method*

General.—Some difficulty had been experienced in maintaining the quality of the components examined in Report No. 2318. Subsequent castings were affected by shrinkage porosity and fairly severe dross and blowhole formation. A modified method of manufacture was tried and the resulting casting examined visually and radiographically.

Method of Manufacture.—This is illustrated in Fig. 10, with dimensional details attached. Modifications included improved feeding arrangements and runners from the base of the mould to provide an even progressive flow of metal. The mould was made in Southampton sand with a core of Southport sand, plus Crulin B, and the metal was cast at 710 deg. C.

Visual Examination.—Slight shrinkage was noted near the runner gates. No other defects were evident.

Radiographic Examination.—Very slight dross inclusions were apparent in one section, but were not considered to be serious.

Conclusion.—The slight shrinkage noted near the runner gate was superficial and was, in fact, fettled off later. Should this defect become more serious, however, it could probably be eliminated by enlarging the gate and feeder. Dross formation was very slight and might be avoided entirely by enlarging the upright runner and gate to lessen the tendency to turbulence.

Dimensional Details.—(1) Downright, 18 in. height by 1 in. dia.; (2) runner, 2 in. by 1¼ in.; (3) runner, 1 in. dia.; (4) riser, 10 in. height by 4½ in. dia. top, 3½ in. dia. base; (5) gate, 6 in. by 1¼ in.; (6) riser, 6 in. height by 9½ in. by 7½ in. top, 8 in. by 4 in. base; (7) riser, 8 in. height by 5½ in. dia. top, 6 in. by 1¾ in. base.

Fig. 11.—Radiograph of Sand Casting.

Report on the Examination of Sand Castings for Messrs. ——, Part Nos. 7619-4 to Specification DTD.298

General.—This report is subsequent to report No. 2318. Considerable difficulty was experienced in maintaining the high quality demanded by Class 1 radiological examination. Radiographs revealed defects which had the appearance of scattered blowholes. This was confirmed upon examination of machined section, but was seen to be confined to the surface of the casting. Figs. 11 and 12 are of a radiograph and machined section respectively, illustrating the nature of this defect. It was suggested that the surface blowholes were caused by impermeable or damp sand, and experiments with sand and mould drying were made. Some defects were still found to be present after these modifications were made, and the effects of extensive chilling to assist progressive solidification were tried.

First Method of Manufacture

This is illustrated in Fig. 13, with dimensional details attached. Green moulds made in Southport/Bentonite sand were tried, and also ones in Mansfield sand, oven dried. The metal was cast at 700 deg. C.

Visual Examination.—No serious defects were apparent.

Radiographic Examination.—Some improvement appeared to have been effected by this modification, as many of the blowhole defects were eliminated, but the castings were affected by defects which produced a general mottled effect on the radiograph. A slice approximately ¼ in. thick was cut from the casting and radiographed. Severe shrinkage was noted.

Examination of Machined Section.—No surface blowhole defects were apparent, although some general porosity was evident.

Micro-Examination.—This confirmed that the casting was severely affected by interdendritic shrinkage porosity.

Mechanical Properties.—Test-bars were cut from a casting with the following results.

	Ultimate tensile strength. Tons per sq. in.	Elongation. Per cent.
1	11.42	6.5
2	8.32	2.0
3	9.04	3.0
4	9.68	4.5
5	11.08	4.5
6	10.64	5.0
7	8.76	2.5
8	10.84	5.0

Remarks.—It was considered that the general interdendritic shrinkage porosity was caused by inefficient feeding. As considerable difficulty would be experienced in increasing the size of the risers, it was suggested that the casting be completely chilled to within 1 in. of the base of the riser.

Second Method of Manufacture

The above modification was adopted. No defects were apparent on visual examination. Radiographic examination showed the casting to be entirely free from defect. An examination of machined section confirmed the absence of any serious form of defect. The following mechanical properties were obtained from test-pieces cut from the casting.

	Ultimate tensile strength. Tons per sq. in.	Elongation. Per cent.
1	13.52	4.0
2	12.32	5.5
3	10.4	5.0
4	13.6	7.0
5	12.0	5.5
6	14.72	7.0
7	10.52	4.0
8	10.0	3.0
9	11.25	5.0

Conclusion.—A considerable improvement in the quality of this component has been effected by the latter modification, and it may be safely adopted for future production. This component and others for the same customer are of particularly heavy section, and, by the original methods of manufacture, have exhibited defects not previously encountered in standard production of components of smaller section. Owing to the extremely heavy section, feeding arrangements without the use of chills would be considerable and, in most cases, due to the shape of the casting, would be impracticable. It is suggested, therefore, that the technique of extensive chilling be adopted as standard practice to all heavy section components in alloy to specification DTD. 298 and DTD. 304.

Dimensional Details.—(1) Downright, 13 in. height by ¾ in. dia.; (2) runner, 7 in. height by 1¾ in. dia.; (3) gate, 3 in. by 2 in.; (4) feeding pad, 7½ in. height by 3½ in. dia.; (5) riser, 5½ in. height by 2½ in. wide top, 2 in. wide base.

Example 3

The final example is a report on a cylinder block casting which had been modified after visual inspection on the first method has shown the presence of severe draws. As variations of section are encountered, tensile tests have been included to check the uniformity of the material.

Report on the Examination of a Cylinder Block Casting for Messrs. ——, Part No. — in Hiduminium RR. 50

General.—This casting was submitted for the approval of the method of manufacture. Visual examination and examination of polished sections were made. Tensile test-pieces were taken from positions indicated in Figs. 14 and 15.

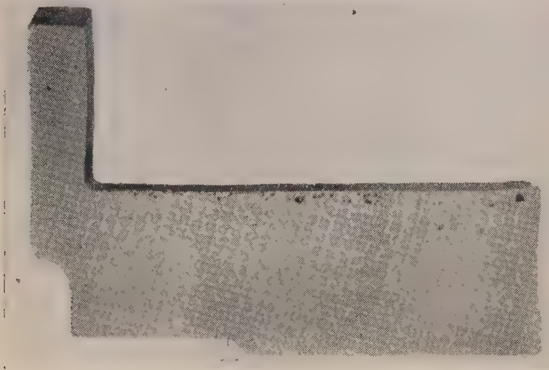

FIG. 12.—No. 3737.

Method of Manufacture.—This is illustrated in Figs. 14 and 15, photographs of the complete casting, with dimensional details attached. Two sets of five downrights were used instead of the double downrights shown in the photograph. The large risers were cut to the extreme edge of the casting and the main runner was extended round the casting, thus providing a more adequate feed. Castings made before these modifications were effected were badly drawn. The jacket core was vented to prevent misrunning. The pattern was moulded in Southampton sand. Cylinder bore cores were made in Mansfield sand and jacket and small cores in Southport sand, plus Crulin B. The base of the casting and the cylinder bores were chilled. The metal was poured at 750 deg. C.

Visual Examination.—No defects were visible on this casting. Previous castings have been drawn, but the modifications mentioned above appear to have counteracted these tendencies.

Examination of Polished Sections.—No evidence of gas or shrinkage porosity was present.

Conclusion.—This casting appeared satisfactory for production. Tensile test results were considered satisfactory for a casting of these dimensions. Owing to the large number of cores employed in the manufacture of this casting, it is considered advisable to pay close attention to the quality of cores and to provide adequate venting to decrease the possibility of porosity and misrunning.

Dimensional Details.—(1) Riser, 5 in. height by 4¼ in. by 2 in.; (2) riser, 5 in. height by 2½ in. dia.; (3) downright, 12 in. by ⅞ in. dia.; (4) runner, 48 in. long by 1¾ in. by 1⅛ in.; (5) gates, 1¾ in. by 1¼ in.

It is not the intention of this Paper to discuss the moulding methods shown, and the examples have not been chosen to illustrate any special features. They are, however, typical of the class of work a light alloy foundry will always encounter, and which necessitate a routine method of examination and recording to enable production to start and to be maintained

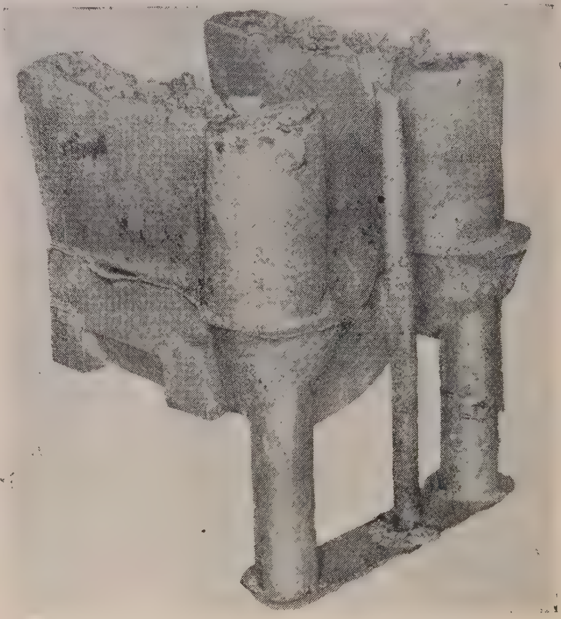

FIG. 13.—No. 3595.

Tensile Test Results (see example 3.)

No. of test piece.	Yield point. Tons per sq. in.	Per cent. elongation	Maximum stress. Tons per sq. in.
1	8.5	3.0	10.4
2	9.7	7.0	12.6
3	9.6	2.0	10.7
4	8.2	2.0	9.2
5	8.4	2.0	8.7
6	8.0	3.0	8.4
7	8.8	2.0	9.5
8	7.3	4.0	8.4
9	7.8	4.0	9.5
11	10.4	3.0	12.2
12	8.5	4.0	9.7
13	8.5	3.0	9.3
14	8.8	3.0	9.6
15	7.7	2.0	8.6
17	8.3	3.0	9.3
18	7.2	3.0	9.7
19	8.9	4.0	10.3
20	8.7	4.0	8.9

with a minimum of difficulty. A casting such as the cylinder block in the final example warrants a far more searching investigation than the sparse details given, but such is not the purpose of the method of attack adopted for routine check purposes. It will be covered by a separate, but parallel detailed development programme, including the results of customer's experience, materials research, effect of production variations, fatigue tests and tests at elevated temperatures, of too lengthy a character to be of immediate use in getting production under way.

It must not be forgotten in planning a scientifically controlled foundry, that the foundryman is essentially a craftsman, and that whereas in many other industries it can safely be predicted that a given result will emerge from a planned procedure, in the manufacture of sand castings the foundryman's craft and experience must still be relied on to carry through successfully a production programme. The information gained by examining castings at any stage must be transmitted in a concise form to the man on the job. In dimensional inspection checks, the old system of inspection in the mass perhaps two or three weeks after casting is giving way to spot face jig methods, with special gauges in set-ups on the actual foundry floor, in order to contact the moulders within the shortest possible space of time.

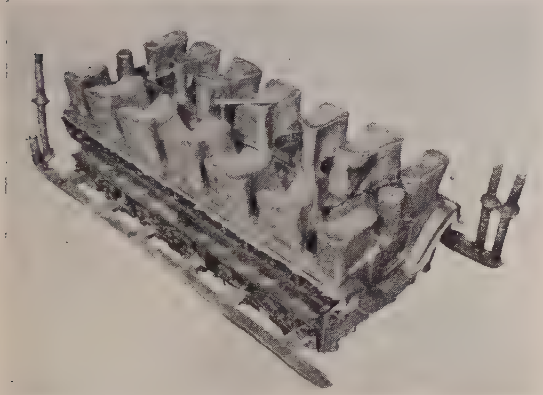

FIG. 14.—NO. 1614.

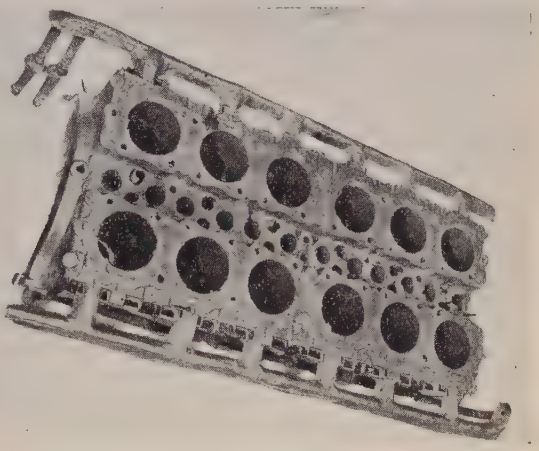

FIG. 15.—NO. 1614.

In the same way, if laboratory control is to be effective it must not be retrospective. The laboratory man must operate from the foundry floor and collaborate with the moulders and furnacemen by personal observation, rapid investigation and exact records, and sum up with clear interpretation and practical recommendations.

In the foundries of High Duty Alloys, Limited, this collaboration is achieved by means of the testing schedule described, and has proved to be of more immediate value than the control testing that is normally done by means of sand testing, tensile and analysis checks and porosity tests, which however provide valuable supplementary information in evaluating the results of "first off" casting examinations.

DISCUSSION

MR. WILLIAMS, referring to the relative position of runners and risers, said it was essential to know just where to put the chills, and how big they should be.

MR. A. LOGAN said he was particularly gratified that this Paper had been presented, for several reasons. One, which he had been advocating for a long time, was that the Institute should pay more attention to light alloys and to making known the advances that had been made in light alloy foundry technique.

Actually, there was little he could discuss in the Paper, because it was a plain straightforward statement of the methods in operation and the manner in which the quality and soundness of the castings were checked as the castings went through. One rather important point brought out in the Paper which tended to be overlooked was that it was not sufficient only to check up a method of casting at the start of a production run and lay down a standard technique for production. It was essential to keep a constant check on the job all the way through. Some people might wonder why that should be, but it was extraordinary how minor deviations and variations took place where the same operation went on continuously over a long period; and therefore a constant check was necessary to prevent undue variations taking place. It was undesirable to start a job off and then disregard or forget it, and this was particularly so in founding, which was still rather more an art than a science. A large number of small variations from the laid-down procedure could creep in, and unless a constant check were maintained, the resulting castings would deteriorate considerably.

Finally, he said that perhaps it was hardly fair to raise a point which was not really covered by the Paper, but one could not help being struck, in looking at the photographs, by the size of the runners and risers. Could the author give a figure for the runner and riser ratio to finished casting weight? It was a point which interested him very much.

Increasing Interest in Light Alloys

The CHAIRMAN (Mr. D. H. Wood, Vice-President), commenting on Mr. Logan's remarks *re* more attention being given to light alloy casting, said that criticism may to some extent have been justified in the past; latterly special arrangements had been made to cover more fully this branch of the industry.

The London Branch was devoting something like half its programme next session to matters connected with the light alloys casting industry and, what was more, he believed they were taking their meetings to the home, or what might be described as the home, of the light alloys casting industry.

Mr. F. H. Hoult added his congratulations to the author for an excellent Paper. With regard to micro-examination as a method of determining the efficiency of casting methods, he asked how much stress should be laid on micro-examination as compared with radiographs. Again, there was the effect of different methods of casting, such as green sand, skin drying and complete drying. There was also the question, with regard to D.T.D.304, whether heavy chilling was justified, and he would like to know what would be the minimum thickness of metal the author would attempt to chill.

Periodic Revision Essential

Mr. S. Welbourn said he was concerned with a number of foundries engaged on light alloy and other non-ferrous and ferrous work and had always been struck by the difference in approach—speaking from the point of view of average and not special cases—between light alloy and other foundries. Probably the main reason was that light alloy castings began at a later date than the other cast alloys and, in consequence, more scientific principles were applied from the very beginning. This, undoubtedly, had been an assistance to the light alloy industry. There was a point which the author had brought out which deserved emphasis, and that was that, once a technique had been developed by which sound castings could be produced, it was not sufficient to say "There is the technique," and then leave the matter and expect long continuous successful running. In the case of jobs which had been run for a number of years, he frequently found that about every six months in some cases, and about every year in others, the same trouble cropped up again and when these were brought to the notice of the foundry concerned they immediately knew the answer. Then the matter was put right. In spite of that, it was impossible to prevent the same trouble coming along at a later date, and therefore it was necessary constantly to be taking steps to keep the castings sound throughout the whole run of the job, which might be for many years or only a few months. Any information which would assist to this end would be of great value to the Institute as a whole.

Author's Reply

The **Author**, replying to the discussion, and expressing his appreciation of the comments that had been made, said the first point raised was the general principles governing the relative position of chills to runners and risers. That was a point on which he felt very strongly the foundryman should have full information in the first place and not have to rely on experience alone. There should be available full information to enable the foundryman to see how a casting should be run to avoid turbulence in the mould, so that the metal entered the mould gently, and preferably at the lowest point, gradually welling up. To do that satisfactorily it was usual to run the casting from the bottom, although this might not give just what was wanted with regard to feeding because the risers were usually best placed at the top, away from the hot metal, as it was easier to mould in that way. In the case of heavier metals, gravity feeding was a major factor as distinct from "blind" risers, but that did not apply so much to the lighter metals. However, in the case of magnesium castings, he was sure they could be perfectly well-made with the risers underneath, but it would be very difficult to mould them in that way. With regard to the effect of chills in relation to the risers, it should be made more widely known that there were certain rules governing the progressive solidification of castings. The casting should be made to solidify at the point farthest from the risers, which should, in general, be over the heaviest section, and directional solidification could be maintained by correct positioning of the chills, risers and runner gates.

With regard to the ratio of runners and risers to casting, mentioned by Mr. Logan, that was probably higher in the case of the light metals than in the case of cast iron, although not necessarily so in comparison with steel or some bronzes. An over-all figure might be given of 60 per cent. for aluminium alloys, rising to 70 per cent. in some cases, although there are many castings in which the proportion might be rather less. It was not easy to give a general over-all figure because castings varied so much.

As to the relative merits of microscopic examination as compared with radiological examination and screening in assessing the quality of castings, mentioned by Mr. Hoult, personally he would regard microscopic examination as of secondary importance in this connection. Radiography was probably the most comprehensive means, and this could be supplemented by fracturing the casting. A great deal could be learned by smashing up the casting. Microscopic examination was not always necessary, and was usually resorted to when one was unable to trace a difficulty by other means. This form of examination was only local, because one was only looking at a very small piece of the surface that had been polished. Normally one would not be examining more than one square inch, which restricted microscopy to a more critical examination of a defect already discovered or investigation of a heat-treatment condition. The other question put by Mr. Hoult was not altogether relevant to the Paper, *viz.*, the effect of skin drying, complete drying and green sand. Perfectly satisfactory castings of varying types could be made with all three methods, although entirely green-sand methods were not used to any extent in light alloy foundries. The majority of castings were skin dried. With regard to chilling, it was not easy again to give a definite ruling which would cover all types of casting. The amount of chilling, the size of the chills and their distribution played an important part in the final result, but considering D.T.D.304 alloy, it might be said that any casting which had a wall thickness in excess of 2 in. would require really extensive chilling.

The important point of the variation of castings in production had been raised by Mr. Welbourn, and the manner in which a characteristic difficulty would arise from time to time was a thing which it was necessary to counter. It appeared to be due to the fact that there was a datum line in the quality of any production of castings, and the closer one was to that datum line the more was there likely to be trouble. It was possible to work very close to the quality limit and get good castings all the time, but the liability of falling into trouble would be greater the closer one was to the datum line. A method might be satisfactory for a number of castings, but, due to the scatter of results which was inevitable in production by one method, certain castings would be below the standard quality, and the datum line must be considerably below the general standard of quality produced by that method before one was entirely out of trouble.

Vote of Thanks

Mr. A. J. Murphy, M.Sc., proposed a vote of thanks to the author.

Mr. F. Hudson, seconding the proposal, said they always expected something good from High Duty Alloys, Limited, and they had certainly not been disappointed on this occasion. One thing in the Paper that had appealed to him was that the principles set out also applied to copper alloys, and the makers of these might well take an interest in it from that point of view. It would be generally admitted that there was great waste of time and money on the part of engineers who had to machine castings which ultimately turned out to be defective. He imagined that the user of non-ferrous alloys would be prepared to pay a high price for castings which could be guaranteed as to soundness, and the methods outlined in this Paper would undoubtedly play an important part in obtaining such a degree of perfection. Apart from the question of price, at the present time it was the duty of every founder to produce the best quality castings—and there was room for improvement in this direction. In these days few opportunities presented themselves for getting together and discussing their many problems, but this afternoon afforded an opportunity to speak plainly on this matter of casting quality. He believed the ratio of defective castings to metal melted in the non-ferrous industry had increased considerably during the past few months, to the detriment of the war effort. The reasons given for this state of affairs were difficulties associated with labour and materials, but he did not share the feeling held by many foundrymen that there was little one could do about it. There was something that could be done about it, and this Paper showed how. On the other hand, in addition to immediate needs, foundrymen were beginning to give some anxious thought to post-war development, and it occurred to him that a foundryman who decided to market castings of guaranteed soundness need have no anxiety in this connection.

The vote of thanks was cordially given.

Paper No 770

Some Aspects of the Production of Malleable Iron Castings

By J. ROXBURGH,* A.M.I.Mech.E. (Member)

In a Paper, entitled "Malleable Castings,"[1] presented by W. T. Evans and A. E. Peace in 1928 to the Leicester Convention of the Institute of British Foundrymen, there occurs the following statement:—". . . In this Paper the authors will endeavour to convince engineers and users of malleable castings that a reliable product from both blackheart and whiteheart varieties can be, and is being, produced by the application of correct methods. . ." That statement was made only fifteen years ago, but to-day it would be quite true to say that the engineer has every confidence in the use of malleable castings for certain applications, if their extensive use and variety of application be taken as a criterion, provided always that such castings are produced under strict scientific control throughout all the stages of manufacture.

The automobile manufacturers, in particular, have long recognised the uniform quality of malleable castings, and the increased demands on the foundry from this source have certainly enabled and encouraged the founders to extend and lay out their plants for greater and speedier production. It follows, too, that during wartime engineers have been quick to realise the potentialities of malleable castings and have utilised them, wherever possible, for applications connected with the requirements of the Services and also, in some instances, for the replacement of materials, such as steel castings and forgings. It is interesting to record that, in the last fifteen or twenty years, the foundries with which the author is associated have increased their output six- or seven-fold, an indication of the progress and development which has been registered.

In the very considerable tonnage of castings thus produced each week, there is a great variety in type, ranging from automobile, electrical, railway, general engineering and agricultural to castings for armoured cars, lorries, guns, tanks, torpedoes, etc., and also in the methods of manufacture, varying from moulding off loose patterns to that by the use of power machines. It is the author's intention to confine his attention, for the purpose of this Paper, to certain aspects of the practice in his foundries and to the description and illustration of the manufacture of certain castings in particular.

Moulding Sands

The moulding sand provided for the moulder in any foundry is of paramount importance and, for many years now, the tendency has been to endeavour to institute a scientific control over such materials in order to produce better castings, with less hazard. Up to three years ago, in his foundries, natural-bonded sands, of the Mansfield variety, had alone been used for moulding purposes, but since then the author has gradually introduced synthetic sand until to-day more than one-third of the output of castings is made in this material.

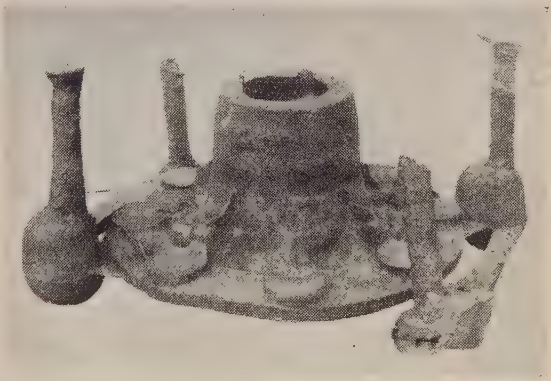

Fig. 1.—Rear Hub Casting with Spherical "Joint Feeders."

With natural-bonded sands, the mixture for facing sand was 25 per cent. red sand, 75 per cent. old sand, with usually 12½ per cent. coal dust for heavier castings and less or no coal dust for the thin and smaller castings. Tests were made on such sands, the results showing 7 to 8 per cent. moisture, 4.5 to 6 lbs. per sq. in. green compression strength, and 18 to 22 A.F.A. permeability number. The high moisture content and low permeability of the sand were apt to contribute to certain defects in the castings, such as drops, scabs, blowholes, etc., and at times, on certain jobs, the percentage of waste was too high, although, generally speaking, the results were surprisingly good. The backing sand, attention to which is sometimes neglected, although it is as important as the facing sand, showed inferior test results.

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* Foundry Manager, Ley's Malleable Castings Company, Limited.

So much excellent work has been carried out by such men as Sheehan, Dunbeck and Walker, and so much information made available to the foundry trade, that the author will content himself by recording, as briefly as possible, his own experiences of the use of synthetic sand for malleable castings.

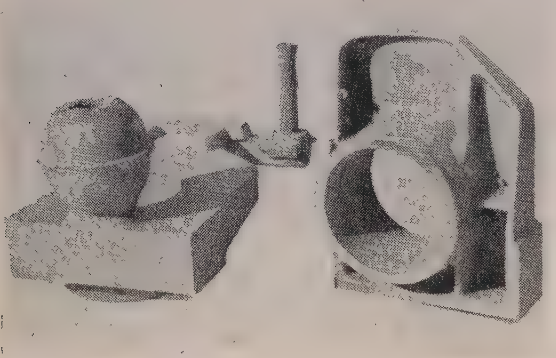


FIG. 2A.—TANK CASTING WITH "TOP SPHERICAL FEEDER."

Changeover to Synthetic Sands

Initially it is acknowledged that with synthetic sands the choice of base sand and the selection of proper bonding material is of prime importance, and with this in mind the author chose a Chelford silica sand for the base sand and bentonite for the bonding material. The method of changeover from natural bonded sands to synthetic sand appears to be a matter for controversy, so the author decided to make a complete changeover by removing all natural bonded sand from the particular moulders' side and replacing it by a synthetic sand made solely from silica sand and bentonite.

The sieve tests for the two varieties of Chelford silica sand, which were available, were as follows:—

	Per cent.	Per cent.
Retained on 10 mesh ...	0.00	0.11
„ 20 „	0.04	0.00
„ 30 „	2.80	0.60
„ 40 „	6.08	1.71
Retained on 50 mesh ..	22.60	6.69
„ 60 „	22.60	14.50
„ 70 „	3.40	10.74
„ 80 „	28.28	27.34
„ 90 „	8.32	20.08
„ 100 „	1.20	7.73
„ 200 „	3.40	9.32
Through 200 „	0.96	0.29

To begin with, a mixture was made up as follows:—100 per cent. silica sand, 3 per cent. bentonite and 3 to 3.5 per cent. moisture, and tests taken showed green compression strength approximately 7 to 8 lbs. per sq. in., with an A.F.A. permeability number of 75 to 80. All the moulding boxes on one moulder's side were rammed up with this material, the castings subsequently removed, and the sand knocked out was used for backing sand. Each day thereafter a facing sand was provided, made up of 20 per cent. new silica sand, 80 per cent. backing sand (referred to previously), 1 per cent. bentonite and 3 to 3.5 per cent. moisture, giving test figures of 6 to 7 lbs. per sq. in. green strength and permeability of approximately 60. The skin of the castings thus produced

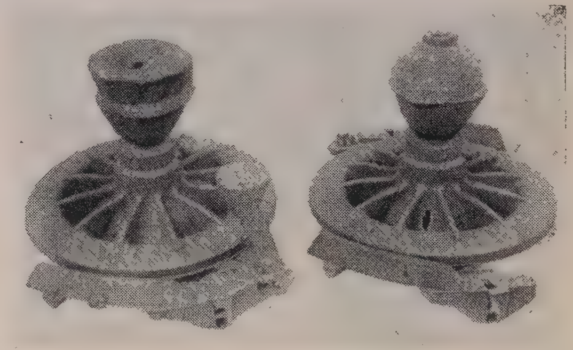


FIG. 2B.—DIFFERENTIAL CASE CASTING, SHOWING COMPARISON BETWEEN USUAL "TOP FEEDER" AND "SPHERICAL FEEDER."

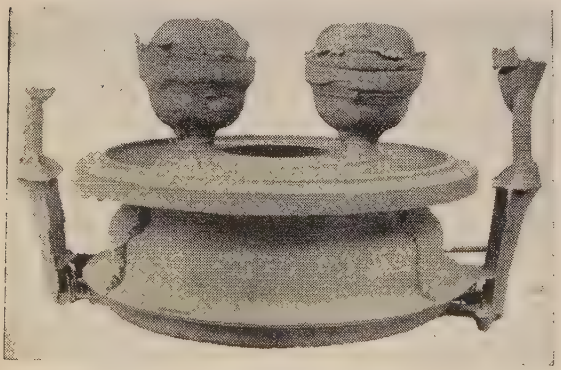


FIG. 2C.—BRAKE DRUM CASTING WITH TWO "TOP SPHERICAL FEEDERS."

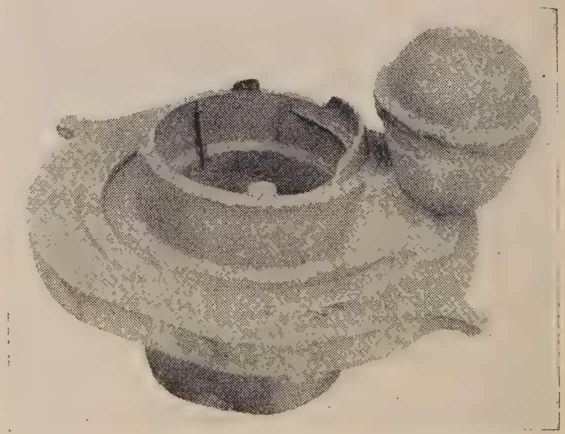


FIG. 3.—HUB CASTING WITH "SPHERICAL FEEDER" NOT ON THE JOINT.

was rougher than that obtained by natural bonded sands and, in addition, the moisture content of the sand was found to be too low for practical purposes, drying out taking place too quickly, and also there was the difficulty of ramming.

It was then decided to standardise a facing mixture containing 2 per cent. coal dust and 4 to 4.5 per cent. moisture, and the skin of the castings was excellent, the sand being quite satisfactory to the moulder, and no further trouble was encountered due to drying out of the sand, as the moulds, except for exceptional circumstances, are cast the same day. The test figures obtained regularly for this facing sand are 6 to 7 lbs. per sq. in. green strength and a permeability of 50 to 60.

Frequent testing of the backing sand was instituted in order to watch its durability, and it was found that, on examination of the facing sand after removal of the casting, only the surface of the sand had been burnt, and there was very little deterioration of the sand below the surface. This was quite an important point, and was to prove very helpful for the future. After further investigation, it was found that the durability of the sand varied with the size and mass of the castings, some backing sand requiring to be reconditioned after three to four months, and others still giving satisfactory results up to twelve months.

The reconditioning of the sand is accomplished by the removal of all the backing sand from a moulder's side to the mill at week-end, and an addition of 25 per cent. new silica sand and 1½ per cent. bentonite usually made. Sometimes the addition of new sand is increased, according to the test results obtained. The backing sand is generally removed for reconditioning, when the tests show 2 to 2.5 lbs. per sq. in. green strength and 75 to 100 permeability. After reconditioning, the sand usually gives 4.5 to 5.5 per sq. in. green strength and approximately 50 permeability.

Bentonite Substitute

The experience of synthetic sand was built up with the use of bentonite as a bonding material, but,

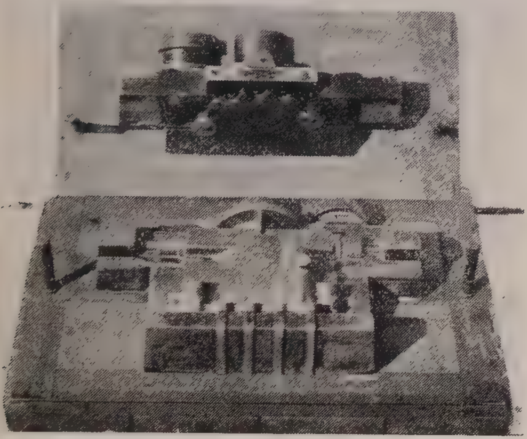


FIG. 4A.—PATTERN TACKLE FOR BEVEL GEAR DRIVE CASING FOR TANK.

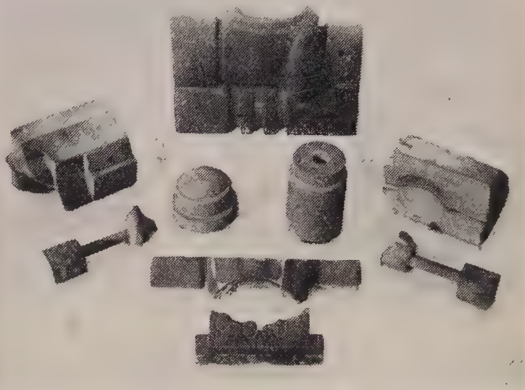


FIG. 4B.—SET OF CORES FOR BEVEL GEAR DRIVE CASING.

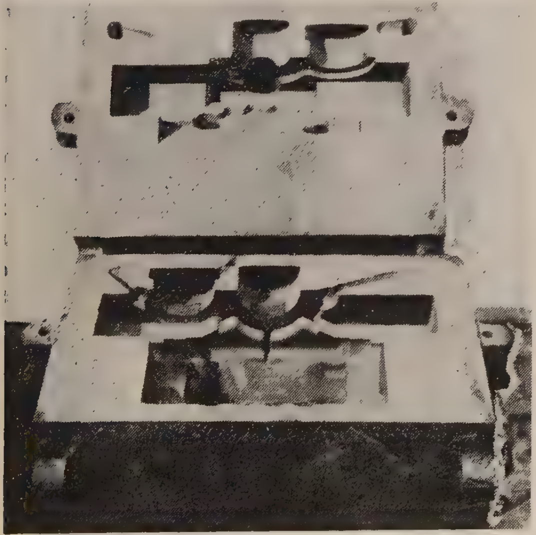


FIG. 4C.—COPE AND DRAG FOR BEVEL GEAR DRIVE CASING.

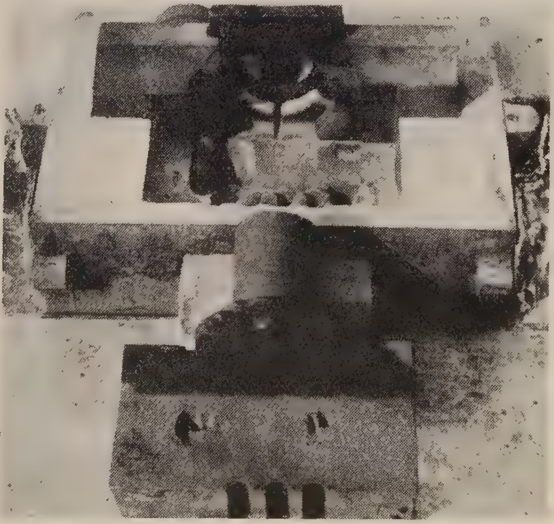
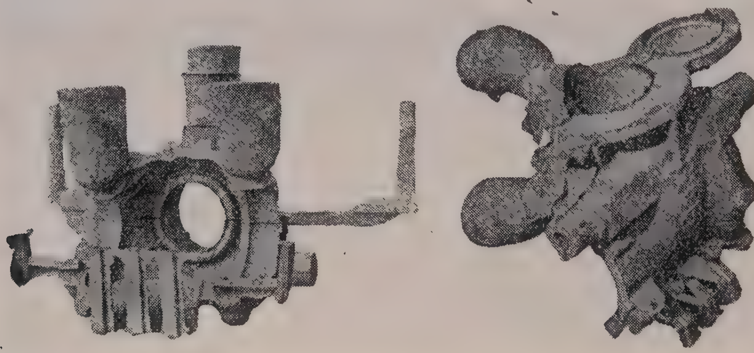


FIG. 4D.—DRAG OF BEVEL GEAR DRIVE CASING BEING CORED UP.

eventually, this material was unobtainable. Before this lack of supply became imminent, many substitute compounds were tried out, but with little success, until Fulbond No. 1 was introduced, since when even better results than with bentonite have been obtained. It has been very gratifying to the author to have been privileged to read the "Second Report of the Moulding Materials Sub-Committee of the Steel Castings Research Committee[2]," wherein it is stated that ". . . Foundry experience has shown that the ramming, casting and stripping properties of the Fulbond mixtures are closely comparable to those of bentonite mixtures, and in reclamation plants the 'life' of Fulbond is proving satisfactory. . . ."



FIGS. 4E AND 4F.—VIEWS OF BEVEL GEAR DRIVE CASING, WITH ATTACHED FEEDERS AND RUNNERS.

There are other points, worthy of mention, in connection with the use of synthetic sand for malleable castings. With the lower moisture content in the sand, it is natural to expect that the metal will run better and remain liquid for a longer period, due to the heating up of the mould. Following from this, it would appear that 'feeders' are more effective in accomplishing their work of producing a sound casting. Solidification is delayed, however, and 'pulls,' or 'hot tears,' sometimes very fine, appear more frequently, particularly where thick and thin sections are juxtaposed. This was more apparent when bentonite was used in the sand, but, since the introduction of the use of Fulbond, the occurrence of such 'pulls' has been reduced considerably. This points to the fact that the hot dry strength of the sand is lower.

For some time now, synthetic sand, after milling, has been put through a disintegrator, and probably this has helped to spread the bond as, undoubtedly,

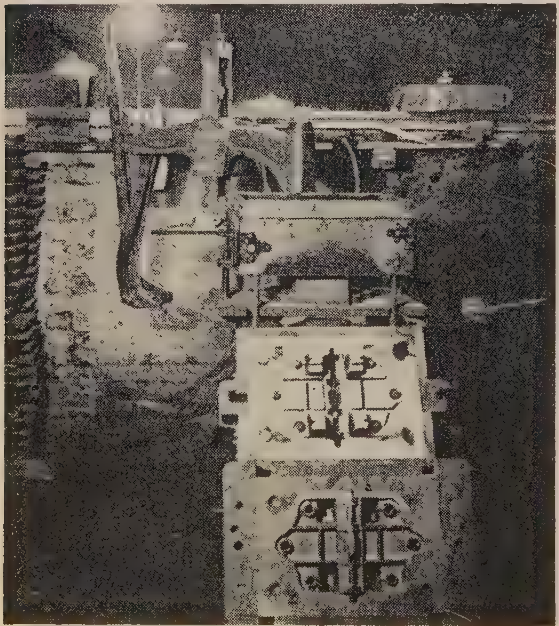


FIG. 5A.—HAND-OPERATED 4-PIN LIFT MACHINE. PATTERN AND DRAG FOR BASE CASTING SHOWN.

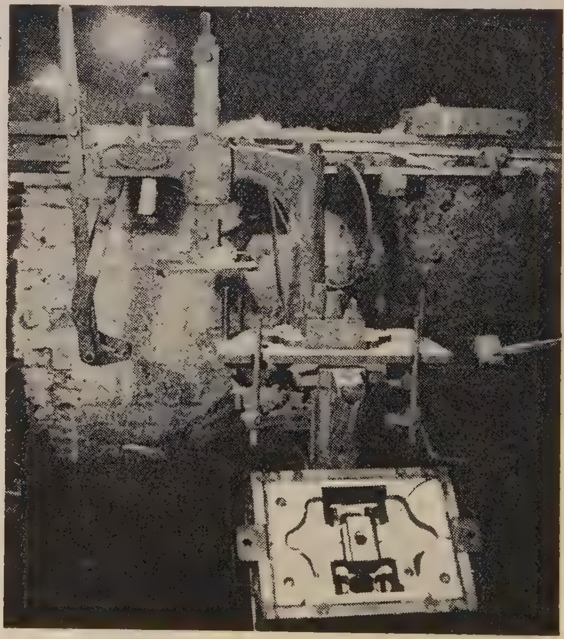


FIG. 5B.—PATTERN AND COPE FOR BASE CASTING SHOWN.

it is recognised that it is difficult to spread the bond evenly over the grains of silica sand and thereby develop the maximum effect of the bonding material. It is felt by the author, and based on observation, too, that this disintegration of the sand has assisted in the less frequent occurrence of 'pulls' on the castings. Such 'pulls' as do occur, however, can be remedied by the addition of suitable 'ties,' which by setting in advance of that portion of the casting, help to avoid rupture. In using Fulbond it was soon apparent that the sand is more easily removed from the moulding boxes than was the case with sand bonded with bentonite.

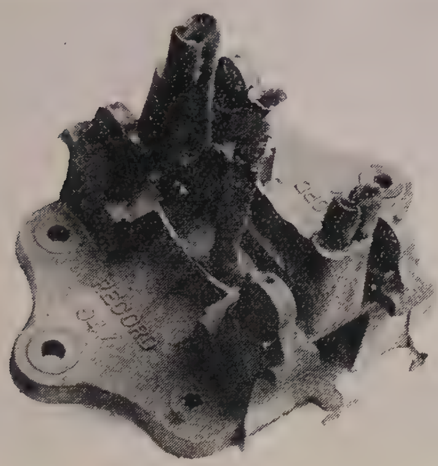


FIG. 5C.—TWO BASE CASTINGS, WITH FEEDERS AND RUNNERS ATTACHED.

Density of Ramming

The density of ramming of moulding sand is another important consideration, and for malleable castings it was found that synthetic sand could be rammed at least three to four times harder than with natural bonded sands, a matter which renders the sand more foolproof in the hands of semi-skilled labour which is used on machine moulding. With natural bonded sands, one knows only too well the ramming density must be more carefully controlled, as well as resorting to greater artificial venting. Synthetic sand has also proved beneficial where pockets of sand have to be carried in a top part for instance and, in some cases, 'lifters' or 'gaggers' have been dispensed with. One matter which requires attention is that sufficient facing sand should be used against the pattern, and that on straight or sloping sides the facing sand should not be allowed to fall away from the pattern, otherwise the metal will eat into or penetrate the backing sand, which is not up to the standard of the facing sand.

Synthetic Sand

By the use of synthetic sand, it has been possible to obtain the benefits of a higher permeability, a slightly higher green compression strength and a lower moisture content and still retain the high quality of casting. Data collected have shown that castings made from synthetic sand have given excellent results on machining and rejects from this source vary from practically nil in some cases up to 1.5 per cent., although the average is less than 1 per cent. It is always a good criterion when the moulder, despite his inclination to be opposed to something new, acclaims the use of such sand, and it has been the author's experience to have been asked by particular moulders if their sand could be changed over to synthetic, because their workmates who are using it have made better castings, and as a result earned more money. Certainly, the author intends to develop the use of synthetic sand still further in his foundries in the post-war period.

Metal Behaviour during Cooling

In the perusal of literature, published over a lengthy period, it is significant to observe the attention which has been devoted to the study of the behaviour of all types of metal in cooling down from their liquid to their solid state, with particular interest for the foundrymen in regard to such metals, when poured into some mould or other, whether it be sand or chill. With all types of metal when cast into any definite shape in some kind of mould, shrinkage is liable to occur.

There are three kinds of shrinkage, entirely different, and occurring at definite stages in the cooling of a metal from its highest to its lowest temperature. During the first stage in cooling, from its highest temperature to its initial freezing point, 'volume contraction' of the liquid metal takes place, which is a definite constant amount for each degree Centigrade fall in temperature. The second shrinkage occurs in changing from the liquid to the solid state, and is usually termed 'liquid shrinkage.' When solidification is complete, after thus having passed

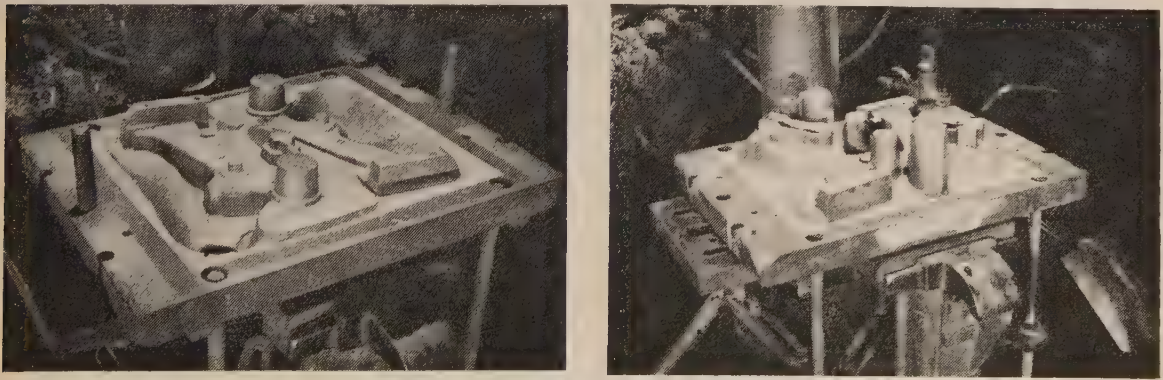


FIG. 6A.—TWIN PATTERN PLATES FOR AGRICULTURAL CASTINGS.

through its 'freezing range,' in cooling down to normal temperatures, another shrinkage takes place, known as 'solid contraction.' These phenomena are well known, but the author offers no apology for their repetition because of their importance.

Phase diagrams are fundamental in the study of the behaviour of all metals and alloys in their cooling down from the liquid to the solid state. In order to be able to cast a metal or alloy into a mould, a degree of superheat must be imparted to it, *i.e.*, a sufficient heat to raise its temperature considerably above its initial freezing point. When cast, the metal, other than eutectic alloys, cools down to its initial freezing point and remains a mixture of liquid and solid crystals, for a certain period, referred to as 'freezing range,' until it is solid. The initial freezing point and the freezing range are determined essentially by the composition of the metal or alloy. During this freezing range shrinkage takes place (the liquid shrinkage referred to previously), forming voids, cavities or unsoundness in the metal. This fundamental knowledge in regard to steel and nonferrous materials can usually be illustrated by phase diagrams, but with white and grey cast irons, due to their greater impurities and multiplicity of compositions, indications of subsequent behaviour can only be forecast approximately or postulated as a result of previous experience with some particular composition of metal.

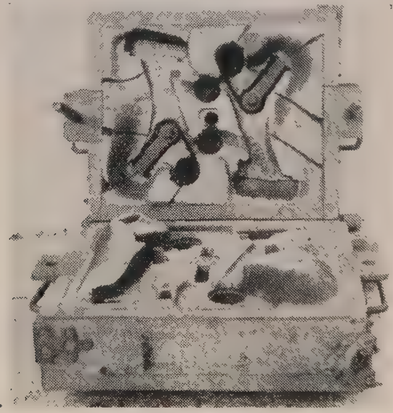


FIG. 6B.—COPE AND DRAG FOR AGRICULTURAL CASTINGS.

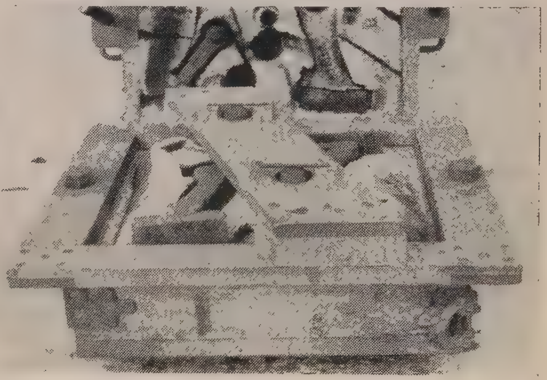


FIG. 6C.—DRAG, SHOWING JIG USED TO CENTRALISE CORES, FOR AGRICULTURAL CASTINGS.

When considering the processes associated with the manufacture of castings, design, mass, differences in section, composition and temperature of metal, and mould materials, all exert their influence on the behaviour of the metal during cooling. It is the constant aim of the manufacturer to control or direct the solidification of the metal, so that appropriate measures may be adopted to produce a sound casting. It is obvious that the last portion of a casting to solidify, if no provision were made for additional metal to be 'fed' into it, would present 'draws,' 'sinks,' or 'unsoundness.'

In order to take care of this 'liquid shrinkage' and to promote the soundness required in a casting, it is essential to provide a reservoir of hot metal from which the casting can draw to fill up the cavities or unsound portions which would otherwise result. Where thick and thin sections occur in a casting, the difficulties of 'feeding' are increased, particularly if the thick sections of the casting, due to the method of moulding adopted, are so placed in the mould as to render them difficult of accessibility. It is preferable, if possible, when moulding, to arrange for the thick section to be above the thin section, so that the thick section can feed the thin section, whilst the thick section can itself be made sound from a reservoir of metal. It often happens, however, due to the vagaries of design, that thick sections occur at various points of the casting, causing further complications due to the difficulty of arranging for the provision of additional metal to ensure their soundness.

It will be recognised then that each individual casting has its own peculiar characteristics with regard to liquid shrinkage, and the necessary measures must be devised to overcome the defects which would result from this cause. It is often possible, due to the happy relations which exist between customer and manufacturer, for a design to be altered in its initial stages, to assist the manufacturer to produce a sound casting.

Variety in Feeder Types

There are many types of 'feeders' in general use, and they vary in shape and size, dependent on the type of metal used, the design of the casting and method of moulding. They differ, too, in their disposition relative to the casting, some being attached to the casting on the top or highest point, some on the side or on some other pre-determined position, according to the location of the different sections of metal, or on the joint or joints of the mould. The direction of solidification of each individual casting must definitely be studied before the final determination of the disposition of feeders and gates in relation to the casting. In the control of such direction of solidification of the metal in the casting, the sections of metal themselves, the heating or cooling of the metal due to the materials forming the mould, have important influences.

There will be found therefore in general practice what are known as 'top feeders,' on the top or high points of a casting, 'side feeders,' either on a joint of a mould, where they may be 'blind' or brought through the upper part of the mould, or situated in some other part of the mould, apart from the joint, and brought through the cope. These types can again be sub-divided into what are termed 'running feeders' and 'off feeders.' The distinction between them is that with the former, metal is run into the feeder and through it into the casting, whilst with the latter the metal runs out of the casting into the feeder. A running feeder, therefore, usually keeps molten for a longer period than an off feeder, and, where practicable, the former is preferred to the latter, although in exceptional cases an off feeder may give the desired result. A feeder is essentially a reservoir of metal, which should remain in its liquid condition until some time after the casting has solidified, thus ensuring that, up to the point of solidification of the casting, the latter has been able to draw the required liquid metal from the feeder to ensure the soundness of the casting.

Some types of feeders undoubtedly dissipate their heat too rapidly, due to the surface area exposed to cooling by virtue of their shape and, in addition with top feeders, to their exposure to the atmosphere; they are therefore rendered prematurely solid, preventing the completion of their function. In order to retard this rapid dissipation of heat and to retain the metal in a liquid condition and at as high a temperature as possible for the requisite length of time for successful feeding, a shape of feeder should be so designed that the surface area is a minimum for the volume of metal deemed necessary, and this bulk of metal should be concentrated where it is required.

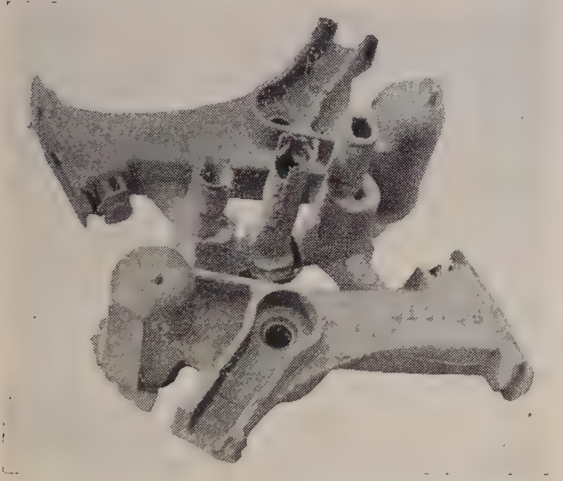
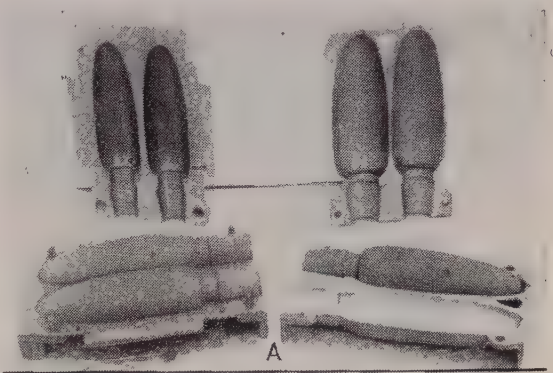


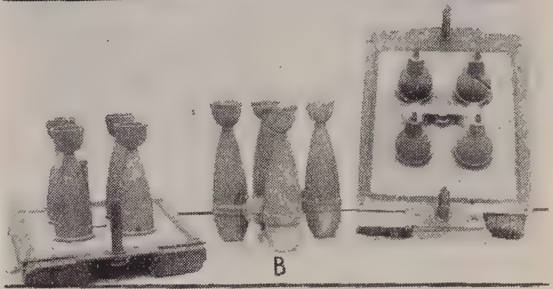
Fig. 6d.—Agricultural Castings, with Feeders and Runners Attached.

Taylor and Rominski on Feeding Castings

It was therefore with very great interest that the author studied the Paper "Utilising Atmospheric Pressure and the Steel Casting,"[3] published by Taylor and Rominski;[*] he takes this opportunity of paying tribute to their work and for the information they have given to the foundry industry in regard to that most important aspect of foundry practice, *viz.*, the feeding of castings. Their work deals exclusively with steel castings, and the author realises that, due to steel having a higher casting temperature and a shorter freezing range than malleable iron, it would exhibit a different 'mechanism of solidification' than the latter when cast into a mould. For this reason, he would not presume to discuss their work in detail, but would take the opportunity of reporting his experiences gained in the feeding of malleable castings. The author's experiments, on a practical scale, will probably prove to be of some assistance.

The metal, which the malleable founder pours into moulds, is a white cast iron, which for blackheart castings usually conforms to an analysis of T.C 2.3 to 2.5 per cent., Si 0.90 to 1.0 per cent., Mn 0.3 to 0.4 per cent., S 0.07 to 0.09 per cent. and P 0.15 per cent. maximum, and in the author's foundries is provided from air furnaces, either hand-fired, of 7 tons capacity, or pulverised-coal-fired of 20 tons capacity. Such an iron must be cast at a high temperature, approximately 1,450 deg. C., and it has a high initial freezing point, a freezing range longer than steel and shorter than cast iron and high solid contraction, all of which create problems for the foundryman. Another complication, too, is that all the metal is of one composition, except for the changes which take place in the bath of metal during the time the furnace is running out (it may be as much as $\frac{3}{4}$ to 1 hr. for a 20-ton heat), and this means that all types of castings, thick and thin, large and small, are cast with the same metal, although some selection can be, and is, made.





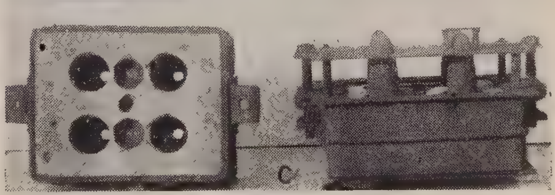
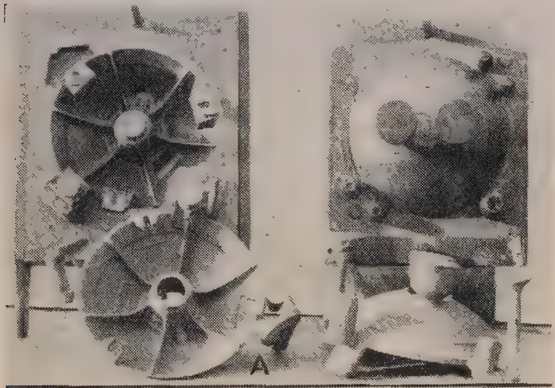


Fig. 7a.—Corebox, Core Drier and Cores for 3-in. Mortar Bombs.

Fig. 7b.—Twin Pattern Plates for 3-in. Mortar Bombs and Castings, with Feeders and Runners Attached.

Fig. 7c.—Cope and Drag, showing Jig and Bridge Gauge used in Setting Cores for Mortar Bombs.

The use of blind feeders has long been in vogue with the malleable founder, and such feeders have been utilised by the author's company for 15 or 20 years. However, three years ago, the author conducted a special investigation on the feeding of malleable-iron castings, and since then the results obtained have been used on a practical scale. Like Taylor and Rominski, the author obviously selected a spherical-shaped feeder, as it had the least surface area for a given volume, with consequent less dissipation of heat, and it was from this fundamental basis that the author developed his subsequent practical applications. At the same time, the author's main intention was to endeavour to increase the yield of good castings from the melt by reducing the amount of metal used for feeders, and, in this, he claims some measure of success, although he had in mind at the same time the greater effectiveness of such feeders.



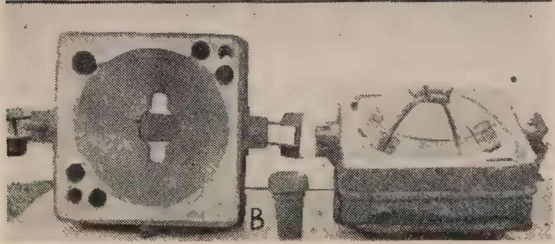


FIG. 8A.—TWIN PATTERN PLATES FOR 21-IN. TORPEDO NOSE, TOGETHER WITH CASTINGS, WITH FEEDERS AND RUNNERS ATTACHED.

FIG. 8B.—COPE AND DRAG FOR 21-IN. TORPEDO NOSE CASTING.

It was evident that, in the past, experience or 'rule-of-thumb' had been the usual guide in the choice of a shape or size of feeder, or of its disposition. Even to-day experience is the ruling principle, but greater thought is now given to each individual casting in a definite attempt to reduce the amount of feed metal and also to improve feeding. On the other hand, it is unwise to 'skimp' feeders too much, because allowance must be made for variations in temperature of casting and of composition of metal. There is still no formula established to enable one to calculate the size of feeders required on any particular casting, but, as savings have definitely been registered, the investigations have justified themselves.

The fundamentals of good foundry practice can be applied to the manufacture of all castings, be they made in steel, non-ferrous, white cast iron or other metals, but each type of metal used presents its own peculiarities to the founder in the actual manufacture of the casting. The gating and feeding of malleable castings offers an opportunity to the founder to overcome problems which have been present ever since the manufacture of malleable castings was introduced.

Gating Malleable Castings

The author has derived a great deal of pleasure and useful information from the perusal of a Paper entitled "Gating Malleable and ArmaSteel Castings[4]." by F. E. Reeves, who in an admirable contribution to literature describes different methods of gating and feeding used in his foundry, and changes that have been made to reduce the total per cent. of scrap.

The gating of malleable castings is a matter which demands great attention to detail. It should be emphasised that white cast iron should be melted under proper conditions, and should carry such superheat as to enable the foundryman to distribute and handle the metal for successful casting. Hand ladles of 60-lb. capacity, filled direct from the furnace and bogies, carrying 6-cwt. of metal, subsequently transferred into hand ladles or shanks, and shanks of 1½-cwt. capacity, are used in the distribution and casting of the metal. The casting temperature of white cast iron is most important as, on the one hand, if on the low side, there is the danger of 'misrun' castings, whilst on the other hand, if too high, greater liquid shrinkage ensues, due to heating up of the mould. In arranging the gating of any casting, it should be borne in mind that the metal should enter the mould in a manner to cause least disturbance or turbulence, and with speedy pouring to fill the mould as quickly as possible. Reeves has found that ". . . most slag is formed in the mould . . . " and ". . . the greater the disturbance of the iron, the more slag will be formed. . . ."

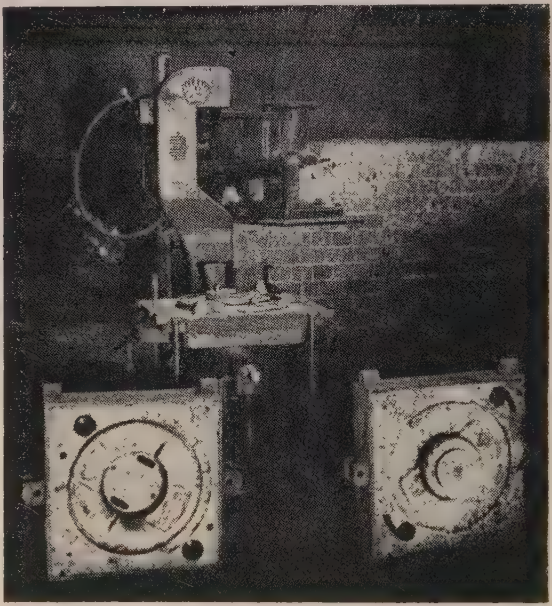


FIG. 9A.—JOLT-SQUEEZE STRIPPER MACHINE, WITH COPE AND DRAG SHOWN FOR TANK CARRIER PLATE.

Many devices are resorted to in an endeavour to ensure that the iron before entering the mould is clean and free from slag, but, despite this, slag occasionally makes its appearance in the casting. A strainer bush, or grid, at the top of the downgate with a grid at the bottom of the downgate is one method used. The grids should be made from a special mixture of oil sand to produce a hard and rigid core, which will not wash or break, for, if fracture or erosion occurs, the sand is taken into the mould. As an alternative to this the 'grid' may be placed on its side, so that it stands up vertically in the runner between the downgate and the casting. The metal, in this way, passes through the grid as opposed to dropping on to it, thus lessening the danger of breakage. 'Spin gates' or 'spinners' are made use of, and gates, where possible, are partly cut in the cope so that any dross may rise to the top of them, so that clean metal only may enter the mould. Sometimes a back runner is incorporated in the gate so as to impart a spin to the metal.

The time taken for pouring different moulds has been observed, and improved results have been obtained by altering the speed of running. The gating of any casting must also be considered at the same time as provisions are made for 'feeding.' Where possible metal is run into the 'feeder,' which is attached to the casting. With some castings, it is only possible to convey the metal into the mould through 'V gits,' and in these cases the feeders must be located on the castings above these 'gits,' or near them, in order that the castings may be sound, where the 'gits' join the casting. Naturally, a hot spot occurs where the metal enters the mould and 'feed metal' must be made available.

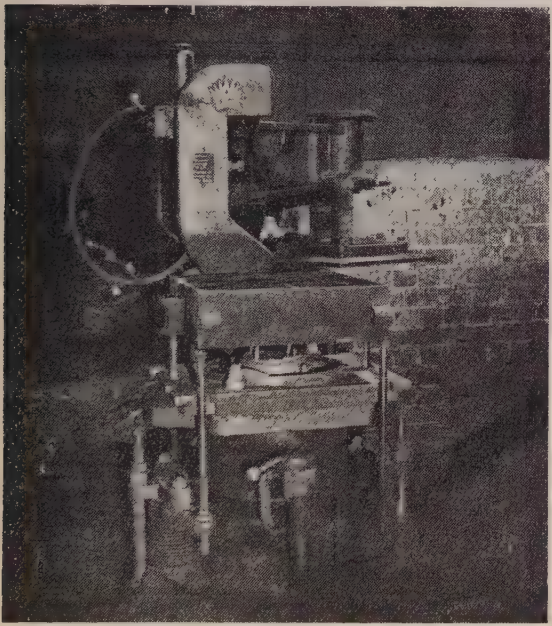


FIG. 9B.—JOLT-SQUEEZE STRIPPER MACHINE, SHOWING MOULD "PUSHED OFF."

Spherical-Shaped Feeders

It had been the custom, in the author's foundries, to use various shapes of feeders according as to whether they were top, side or joint feeders, but, as referred to previously, the author, where possible, introduced a spherical-shaped feeder or a modification of this type for the reasons already explained.

It was found possible to substitute joint blind feeders by spherical-shaped ones (Fig. 1), thus reducing the amount of metal required. Varying sized spheres, ranging from 1½ in. dia. up to 5 in. dia. and stepping up in ¼-in. size in diameter, were made available, and the most suitable size discovered by sample castings which were broken up. Sometimes it was found necessary, still retaining the bottom half of the sphere, to increase the height of the top half by introducing a cylinder 1 in. or 2 in. long between them. All these types of feeder are mouldable, and the shape of the feeder enabled the metal to retain its heat longer and rendered feeding more effective. With some castings, the bottom half of the feeder could be dispensed with and a feeder used shaped as a cylinder with a hemisphere superimposed. Such feeders are useful when joined to a vertical wall of metal.

Feeders on top of a casting, in the past, have been invariably cut through the cope of the mould and very often supplemented by the contents of a bush placed above the mould, in order to increase the depth of the feeders. The top surface of such feeders is exposed to the atmosphere and cools more quickly than desired and the feeders very often have to be made larger for this reason. The author introduced a method which he claims to be quite novel, not only in the saving of feed metal used, but also in retaining its heat. The top feeder used is again spherical in shape (Fig. 2, A, B and C). The bottom hemisphere is moulded and the top hemisphere formed in a core, which has a hole in the top through which metal can be added. This core not only 'stops-off' the length of the feeder and forms a spherical shape, but helps to retain the heat of the feed metal.

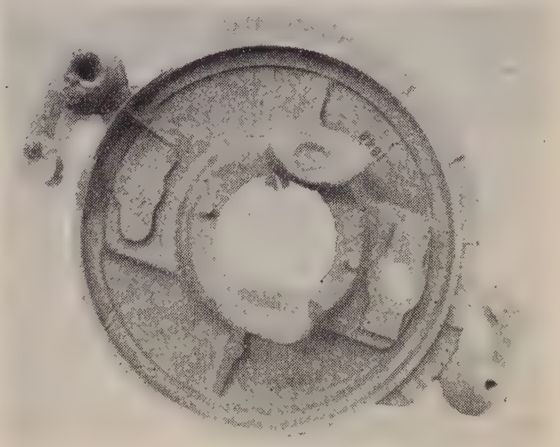


FIG. 9C.—TANK CARRIER PLATE CASTING, WITH FEEDERS AND RUNNERS ATTACHED.

The feeder pattern made use of is loose, and consists of a hemisphere at the bottom with a block print above, the length of which carries it through the cope. The feeder pattern is withdrawn from the mould, and the stop off core, to form the top half of the sphere, is inserted in the print. All cores are made from a standard corebox and are therefore the same length. The core may come level with the top of the box; it may project beyond, or the core may even be placed on the top of the box, when, of course, it must be filled up by extra metal, as it is above the level of the mould. If the top of the core comes below the top of the box, sand can be rammed above it.

This type of feeder is used on the top as well as on the side of castings (Fig. 3), not on the joint; the length of the feeder in the latter case is reduced by a stop-off core to form a spherical shape, the same procedure as with top feeders. These spherical-shaped feeders are very effective and a great deal of metal is withdrawn from them by the casting, sometimes only a shell of metal remaining, if the metal is particularly hot.

Suitability of Spherical-Shaped Feeders

There may be divergent opinions as to the reason for such spherical-shaped feeders, the top half of which is formed in a core, being so effective, apart from the obvious reasons that the metal is protected from the atmosphere and also that a sphere dissipates its heat less rapidly. Although not quite analogous to the introduction of a small core in a feeder to prevent the formation of a crust and thereby permitting atmospheric pressure to be exerted on liquid metal, as developed by Taylor and Rominiski, yet maybe the atmosphere plays its part, due to the increased permeability of the 'stop-off core.'

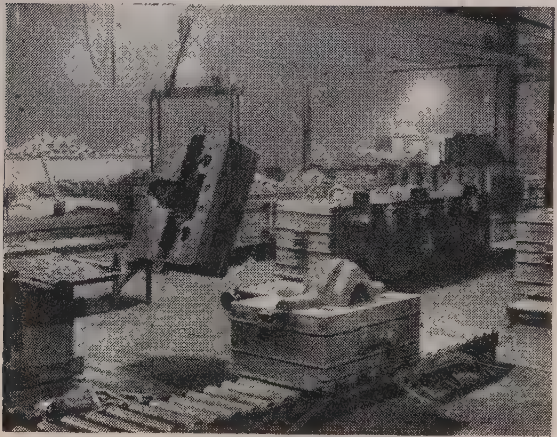


FIG. 10A.—DRAG, WITH CORE IN POSITION, AND COPE, READY FOR TURNING OVER, FOR THREE-TON LORRY AXLE HOUSING. IN THE BACKGROUND, MOULDS READY ON CONVEYOR FOR CASTING.

However, a malleable feeder does not crust over so quickly as a steel one, but the author has made certain observations in regard to this matter during his experience. On different occasions, for instance, joint feeders from the same casting have been examined from different casts. In one case the top surface of the feeder remained liquid whilst feeding continued, and the sink hole was visible on the top of the feeder. In another case, a crust a half-inch thick had formed on the top of the feeder and no sink hole was visible. These two feeders were subsequently weighed, and there was no appreciable difference in their weight. The crust of that feeder, with no sink hole visible, was eventually chipped through, and the feeder was found to have sunk appreciably. In both feeders referred to, therefore, the metal had been withdrawn by the casting to the same extent, despite the fact that one was frozen over at the top and the other had remained liquid. These observations are not casual, as the author has noticed this behaviour quite frequently.

Application of Chills

The methods in use to obtain a sound casting would not be complete without reference to the application of chills to castings. Generally speaking, the use of chills should be avoided, wherever it is possible to obtain soundness in a casting by feeding or by some other means, such as change of design. On the other hand, however, chills, properly applied, can give successful results. For instance, a thick part of a casting due to its isolated position may not permit of feeding, but a chill suitably placed may render it solid. Again the combination of a chill and feeder is sometimes practised with good effect. A chill placed at the bottom of a section of metal, fed by a top feeder, may help to reduce the amount of feeding metal required, due to the action of the chill in accelerating the progressive solidification from the bottom upwards. Chills, too, are used in cores to solidify some thick section or junction of thick and thin sections occurring in a casting.

With thick sections it is often imperative to use chills in order to ensure such sections being 'white,' or in other words to be free from mottle and primary graphite. It is well known that the occurrence of primary graphite in a casting is most undesirable as, after annealing, such a casting is weaker than ordinary cast iron.

It is as well to mention, although quite familiar to all foundrymen, that there is always a danger that the metal will 'kick' off a chill, causing blowing, the gas generated being liable to be trapped. Reeves states that ". . . for good results, chills must be

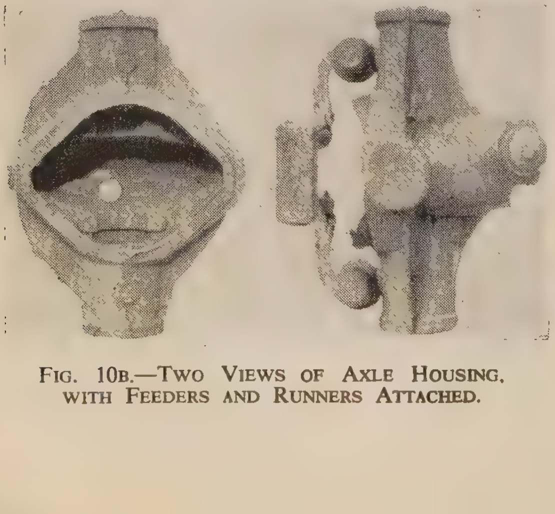


FIG. 10B.—TWO VIEWS OF AXLE HOUSING, WITH FEEDERS AND RUNNERS ATTACHED.

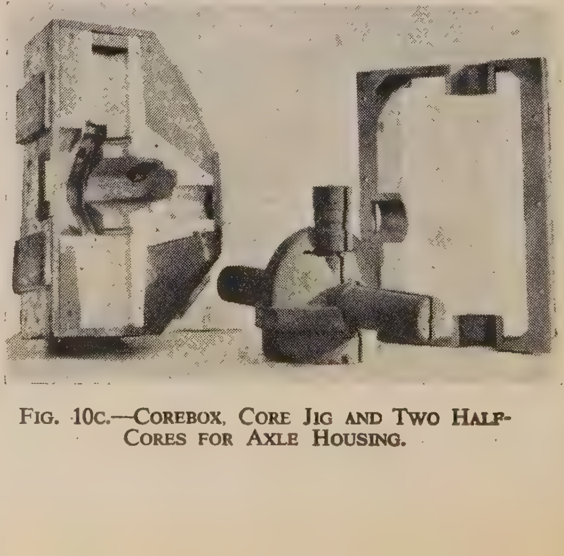


FIG. 10C.—COREBOX, CORE JIG AND TWO HALF-CORES FOR AXLE HOUSING.

absolutely dry, free of rust, and above all must be properly placed in mould or core. . . ." Various coatings for chills have been the subject of experiment, but the author advocates the application of a thin coating of a proprietary oil compound, which usually consists of dextrin and linseed oil.

Economy in Metal

The yield of good castings from the metal melted is always an important consideration in any foundry, and the author has been able, by careful investigation and by resort to the methods outlined, to effect economies in the amount of metal required to produce a certain tonnage of castings, which affects melting costs, cost of metal lost in melting and other ancillary charges in addition.

In the location of feeders on the casting, due consideration should be given initially to ease of grinding, and as little as possible should be left on the casting at a point easily accessible. There is quite an art, too, in moulding the 'break off' where the feeder joins the casting. If not properly moulded, when the feeder is subsequently knocked off, a piece may be broken out of the casting. The feeders and mouths, connecting to the casting, should not freeze until the casting has completely solidified. Where possible, feeders should not be attached to the casting at points which are to be utilised later for location by the machinist, particularly for mass production machining. At times, location points are altered by mutual agreement, to accommodate the founder's arrangements for successful feeding of a casting.

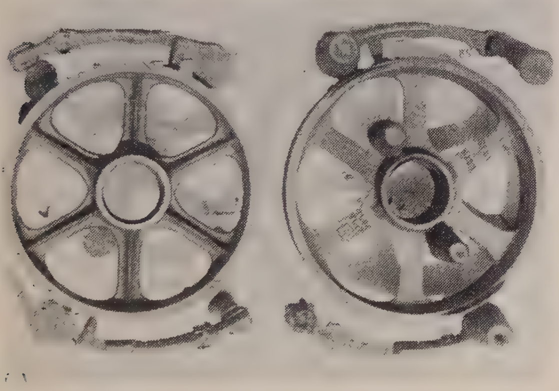


Fig. 11a.—Two Views of Tank Wheel Casting, with Feeders and Runners Attached.

It is obvious that castings for repetition machining must be extremely accurate in regard to dimensions and freedom from distortion. In order to achieve this accuracy, within foundry limits, all tackle supplied, patterns, coreboxes, moulding boxes, etc., should be of the highest quality. It is incumbent on the manufacturer, too, to institute a high standard of inspection at as many stages as may be deemed necessary during manufacture and to safeguard, finally, that no casting be released to the customer which does not reach a definite standard.

Floor and Bench Castings

Owing to the small number of castings required or to the non-suitability of a job for machine moulding, such a job is made loose on the floor or bench. Under such circumstances thought must be given to gating and feeding, and the arrangements should not be left entirely to the moulder himself. Loose or fixed runners are provided and feeder pads screwed on the patterns, and suitable feeder patterns made available. In this way sound castings are produced and feeders and gates kept within reasonable limits as regards size. Occasionally, large quantities of large and intricate castings are ordered and quicker methods of production must be instituted.

Fig. 4 illustrates a casting which was made on the floor with a special lay-out. Although the casting was intricate, the pattern was printed up such that a flat joint was possible. The two half-patterns were mounted on boards and moulding boxes supplied, made specially for the job. The top and bottom moulds were rammed by separate moulders, and one moulder was engaged fully on closing operations. Fig. 4a shows the pattern tackle, Fig. 4b the cores, eleven in number; Fig. 4c, the top and bottom parts of the mould; Fig. 4d, coring up in progress; and Figs. 4e and 4f depict two different views of the casting, together with runners and feeders. This casting is a bottom bevel gear drive casing, weighs 62 lbs., and is used on a tank. The method adopted for its manufacture considerably simplified and increased production.

Machine Moulding

For castings, where regular orders are obtained, and which lend themselves to production on moulding machines, hand and power operated machines are utilised, and some examples will be described. Figs. 5a and 5b illustrate two hand-operated four-pin lift machines, the twin pattern plates being shown together with the top and bottom part moulds in flasks. Fig. 5c is a view of the two castings made in these moulds and the method of running and feeding adopted. It will be noticed that the metal enters the mould on the joint, being sprayed into each casting, whilst the feeders are located at a higher level on the castings, in order to feed a heavy section, these feeders being placed on top of cores in order to make this possible. With a view to keeping the feeders hot, metal is run into the feeders through a hole in the cores.

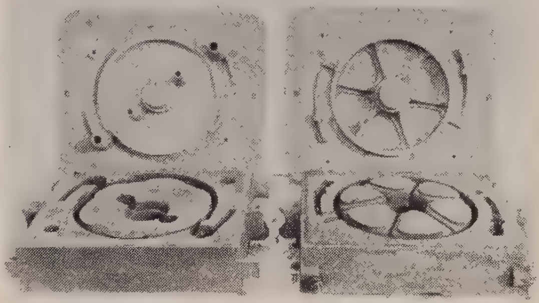


Fig. 11b.—Twin Pattern Plates, with Cope and Drag for Tank Wheel Casting.

Sometimes, it is necessary to manufacture on these hand machines castings which have irregular joints for moulding. An example of such a casting is shown in Fig. 6a, which depicts the twin cast plates. Fig. 6b gives a view of the top and bottom part moulds, whilst Fig. 6c shows the bottom part cored up and a jig, located by the pinholes in the flask, serving to centralise two round cores. The castings produced are illustrated in Fig. 6d, the runner and feeders being attached.

Jolt-Squeeze Machines

Another type of machine used in the author's foundry is the jolt-squeeze machine, which accommodates standard sizes of steel moulding boxes, 15 in. by 12 in., 17 in. by 13 in., and 17 in. square. The boxes are 6 in. deep, but at times frames are used to increase the depth. Fig. 7A shows a layout for 3-in. trench mortar bombs, four patterns being mounted on twin plates for a 17 in. by 13 in. steel box. The spherical feeder should be noted, together with top feeders. These castings were made vertically, primarily because they have to undergo a pressure test and also so that the core may be placed central and at the correct height, in order to give the required volume inside the casting, a vital matter. In Fig. 7B the cores have been placed in position in the bottom part of the mould, and a jig, located from the pinholes of the box, is used to centralise the cores, and a further gauge, shown, to govern the depth of the cores. The bottom print on the pattern is made nearly as large as the casting diameter, so that the metal itself holds the core down. Fig. 7C shows the corebox, provision being made for blowing two cores simultaneously; the core driers are also illustrated.

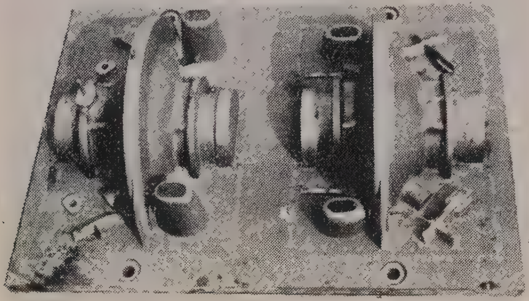


FIG. 12A.—PATTERNS FOR COPE AND DRAG MOUNTED ON ONE PLATE, FOR TANK HUB CASTING.

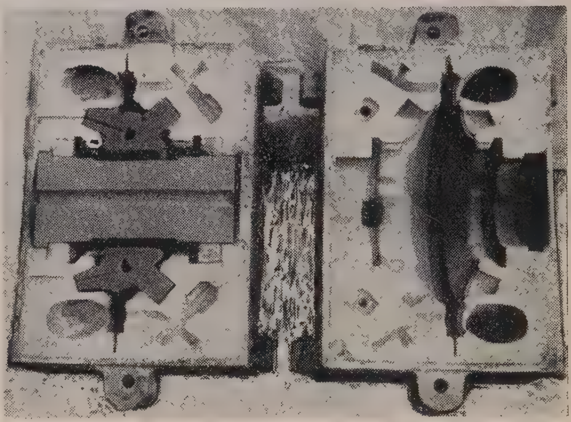


FIG. 12B.—COPE AND DRAG, WITH CORING UP IN PROGRESS, FOR TANK HUB CASTING.

Another interesting job undertaken in the author's foundry is a 21-in. torpedo nose piece, the moulds for which are made on a similar jolt-squeeze machine, but in this case 17 in. square steel boxes are utilised. The twin pattern plates and the castings are shown in Fig. 8A. The arrangements for running and feeding are illustrated, the top feeders being knocked off actually when hot. In Fig. 8B are shown the top and bottom parts of the mould, and better results on this particular casting were obtained after synthetic sand was introduced as better venting and running were obtained. These castings are liable to crack, and, as a consequence, every casting is placed in an oven as soon as it is set and whilst it is still red hot, in order to avoid this possibility. Such castings undergo machining all over the outer surface and are subjected finally to a pressure test.

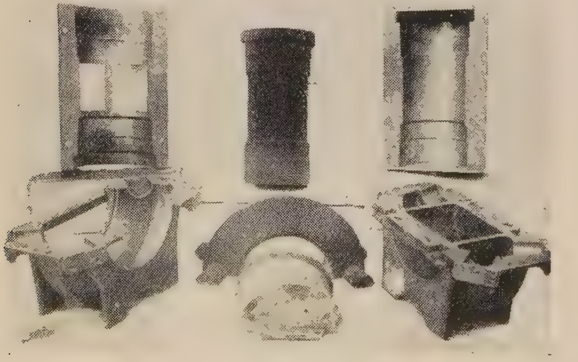


FIG. 12C.—COREBOXES, CORES AND CORE JIG, FOR TANK HUB CASTING.

A further example of a high production machine is the jolt-squeeze stripper or four-pin lift machine. This is illustrated in Figs. 9A and 9B, where the twin plates are mounted on the machines, Fig. 9B showing a mould pushed off and Fig. 9A giving a view of the two parts of the mould. The casting, shown in Fig. 9C, has the runners and feeders attached, and is a plate used on a tank. Excellent castings have been produced by this method, and synthetic sand is again used for moulding.

Use of Jolt Roll-Over Machines

With larger castings, requiring regular high production, jolt roll-over machines have been found to be very successful indeed. Fig. 10A gives a view of a typical layout used in conjunction with such machines, showing the roller conveyors from the machines, and the moulds, by a transfer bogie, are then conveyed on to further roller conveyors for casting. The

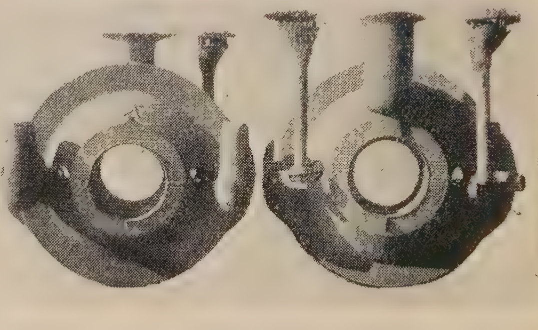


FIG. 12D.—TWO VIEWS OF TANK HUB CASTING, WITH FEEDERS AND RUNNERS ATTACHED.

bottom part of the mould is shown cored up, whilst the top part is being turned over previous to closing. It should be noted that the core has been lightened out and rammed up with black sand, to take care of contraction. The moulds already closed and clamped can be seen in the background preparatory to casting. In Fig. 10B the outside and the inside profiles of the casting are depicted. This casting weighs over 1 cwt. and is the axle housing for a 3-ton lorry. The running and feeding arrangements are shown, and many ties are required on such a casting to counteract the occurrence of "pulls" or "tears."

In order to facilitate coring up, the cores supplied to the moulder should be accurate and should require no attention by the moulder whatsoever, except to saw-cut a tie which cannot be placed in the corebox. Each half-core made is placed in a cast-iron jig, a partial facsimile of the mould, with the joint and bearings accurately machined and the core rubbed off to accurate size. In Fig. 10C will be noted the half-corebox, two half-cores after jigging and the core jig itself.

Another type of casting laid out for quantity production is illustrated in Fig. 11A. The moulds, shown in Fig. 11B, are made on a jolt roll-over machine coupled up to a roller conveyor system. This casting is a wheel weighing 52 lbs. and is used on a tank. In Fig. 11A the method of running and feeding is clearly depicted. It will be noted that two side feeders are attached to the centre boss. At one time one top feeder on the boss was used, but a great amount of grinding was necessary to templet, too, and also such feeders were knocked off 'hot.' The two side feeders proved to be quite successful and there is very little grinding to be carried out after they have been knocked off. This casting takes 14 secs. to pour, and it will be noted that there is a 'grid' placed at the bottom of the downgate and a further one placed vertically in the runner gate. In addition half of the gate is moulded in the cope, whilst the 'V git' is in the bottom part of the mould. These precautions are taken to ensure the cleanliness of the casting.

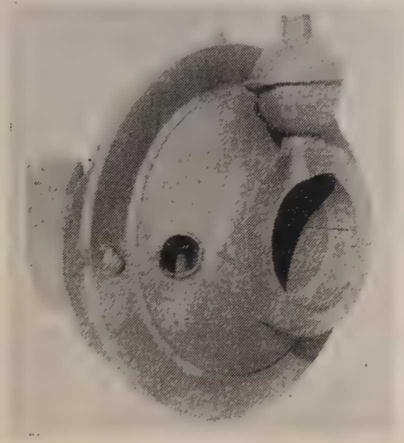


FIG. 12E.—TANK HUB CASTING, WITH "TOP SPHERICAL FEEDER." COMPARE WITH "TOP FEEDER" SHOWN IN FIG. 12D.

A further illustration of castings produced on a jolt roll-over machine is provided in Figs. 12A, 12B, 12C, 12D and 12E. In this case, see Fig. 12A, two half-patterns are mounted on each machine, and two moulding boxes used so that each machine can produce one complete mould, the two machines used simultaneously, thus producing two complete moulds. This casting is a wheel hub for a tank and weighs 98 lbs. In Fig. 12B will be seen the two parts of the mould, with coring up in progress in the drag. It will be noted that in addition to the bore core, there is a chamber core, with four outlets, two of which are used to carry off the gases. The cores are shown in Fig. 12C. The half-corebox for the bore cores is shown at the top of the picture and a jig is used to ensure the accuracy of the two halves. In the lower half of the picture the corebox for the chamber core is illustrated. In the centre of the photograph, a dried chamber core is shown, with the core drier extracted and placed in front of it. Two views of the castings are shown in Fig. 12D with the runners and feeders attached. Synthetic sand has again been used for the moulds. Fig. 12E shows a view of the same casting and illustrates clearly the difference between a 'ball feeder' and the usual top feeder.

Conclusion

The author has purposely confined his attention to certain aspects of the production of malleable castings, but nevertheless has been able to deal in some detail with the use of synthetic sand, gating and feeding of castings, and with some methods of moulding carried out in his foundry. Such matters as construction of patterns and coreboxes, coremaking and other important considerations, must be left perhaps for some future occasion. The author hopes that he has been successful in directing the attention of the reader to the important aspects which he has endeavoured to discuss, and to the development work which has taken place in recent years in the foundry practice associated with the manufacture of malleable castings. The engineer has certainly displayed a keen interest in the products of the malleable industry, and it should always be the founder's aim, not only to sustain it, but, by virtue of the maintenance of quality of casting and by the introduction of further improvements, to enhance that interest.

In conclusion, the author wishes to acknowledge the permission given by the directors of Lev's Malleable Castings Company, Limited, to publish this Paper.

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DISCUSSION

A Revised Specification Sought

The discussion was opened by MR. G. R. WEBSTER, who drew attention to the first paragraph of the Paper, containing a quotation from the 1928 Paper of W. T. Evans and A. E. Peace, to the effect that a reliable product from both blackheart and whiteheart varieties of malleable castings was being produced, and Mr. Roxburgh's own statement that the engineer had every confidence in the use of malleable castings for certain applications to-day. Whilst agreeing with both those statements, Mr. Webster complained that the current specification for malleable castings was quite out of date, and he urged that the I.B.F. should help to produce a new specification now which would assist engineers and designers in the design of their plants.

It was well known, he said, that the existing specification could be met very easily by the "backyard foundry." Certainly the yield point, which was of great importance, should be included in the new specification, for it was on that factor that the engineer was able to design his plant. Every effort should be made immediately—and war-time was not inopportune—to bring forward a new specification, for immediately on the cessation of hostilities the industry should be ready to go right ahead. Certainly the existing specification would hinder the industry's progress.

MR. H. H. SHEPHERD complimented Mr. Roxburgh upon his very interesting survey of modern malleable foundry technique. On the question of producing a new specification for malleable castings, he said the Committees of the Institute and of the B.C.I.R.A. were working together, and ultimately the malleable castings specifications would be such that engineers would feel they had available a product which they could use to a greater extent than it had been used in the past.

Spherical-shaped Feeder

With regard to the use of the spherical-shaped feeder, he said that unfortunately there was a tendency among many patternmakers to avoid its use. They would agree that the job could be done with the spherical-shaped feeder; but often when the pattern reached the foundry one found that the shape of the feeder was anything but that which was designed to enable the founder to overcome the troubles that were likely to arise. Troubles would arise if one did not devise a feeding head which would give maximum feeding facilities and the minimum of difficulty from local crystallisation. Mr. Roxburgh's Paper would have been well worth while even if it had been confined merely to emphasising those points.

The malleable founders in the United States had suffered in very much the same way as the malleable founders in this country. From time to time statements had been published decrying the efforts of the British malleable castings industry, and pointing to the industry in the United States as an example of a 100 per cent. effort. The fact was, however, that until the outbreak of the war the malleable trade in the States was declining rapidly. But, even when there was a decline in production generally, some firms were actually increasing their production. The reason was that they were always up-to-date in their methods and would not allow any antiquated practice; those organisations, and some foundries in this country, were producing castings in malleable iron such as the engineers would not have dreamed of entertaining at one time, and they were getting very good service from them. If one compared the figures of malleable iron production in this country with those of any Continental country or the United States, one would find that, proportionally to the populations, this country was doing as well as any. It was all very well to quote figures of 700,000 tons for America and 60,000 tons for Great Britain; but proportionately this country was not behind. He mentioned the matter because he was a firm believer in the future of the malleable industry, if the malleable industry itself would be a firm believer in its own future.

Chill Coatings

Whilst he had no criticism to make of the practice of coating chills with a core oil or similar type of oil, Mr. Shepherd said that in his experience it was a good plan, for some jobs in malleable form, to shellac the chills and to dust them with very fine sand; but care must be exercised to ensure that the sand was not dusted on to the chill thickly. He used the burnt or dead material from annealing pot bating suitably crushed. He did not claim originality for this method, it had been published both in this country and in America; but in his experience it did help to increase the life of chills and to prevent their sticking.

Again, if one used chills which had become badly scaled one would probably find considerable thickening of the chills and also—a more dangerous occurrence from the point of view of the malleable castings producer—the presence of primary graphite. He had not studied the problem very deeply yet, but he and his colleagues were inclined to the view that it was due to the effect of oxide coating on the chill, on the molten metal; that effect was a type of inoculation which resulted in the precipitation of primary graphite. When this occurred he had cured the trouble by replacing the old chills by new ones.

Finally, with regard to sands, he asked whether the bentonite which Mr. Roxburgh had used was of the western or southern variety. The bentonite which came into this country at one time, he said, was of the western type, which was not very useful to the malleable founder; it gave rise to cracks and other troubles, because it possessed very high hot and dry strengths. He had adopted Fulbond, the new British substitute for bentonite.

Density of Ramming and Tears

MR. G. R. SHOTTON thanked Mr. Roxburgh for a paper which was practical in the best sense of the term, in that it dealt with technique and not merely with method. With regard to the use of synthetic sands, he referred to a statement in the paper that, due to the lower moisture content, there was delayed freezing of the casting and a consequent increase in pulls and tears. Whilst he could not contradict the statement, he suggested that a factor which governed to an even greater extent the occurrence of pulls and tears was the density of ramming. This supposition was confirmed by the statement elsewhere in the Paper to the effect that, presumably owing to the greater permeability of the synthetic sand, "it was found that synthetic sand could be rammed at least three to four times harder than with natural bonded sands. . . ."

As to the statement that the backing sand used had shown an increase in permeability through continued use, and that when the sand was re-conditioned the permeability was reduced again to 75 or 100, Mr. Shotton asked for further explanation, because he did not understand why that should be so.

Coming to the photographs of castings and the runners and risers used, he said the author appeared to have achieved almost the impossible in some cases; it was an outstanding achievement to have done so much with so little feeder metal. In the case of the tank hub casting in Fig. 12, it was surprising that such a very heavy flange around the centre of the casting could be made completely sound with simple joint feeders, where the heavy section was at a higher level than the feeder. Where there was a light section above the feeder it was satisfactory. Of course, the casting temperature was an important factor in dealing with that casting, and presumably the casting temperature was as low as possible in order to ensure that the metal at the top of the mould would freeze rapidly.

He did not think that atmospheric pressure feeding would be very applicable to malleable foundries, in view of the long freezing range; whilst that did not affect gravitational feeding, it might be found very difficult to force the metal up-hill under atmospheric pressure whilst it was passing through that very pasty condition within the freezing range.

MR. A. E. MCRAE SMITH asked if the author had had experience of using jet type runners on top of the spherical feeding head. He wondered whether it would still be possible to cut down the size of the spherical feeder by running through the feeder itself, particularly through the top of the feeder.

Venting and Permeability

Mr. R. C. Tucker, discussing the change from natural to synthetic sands, mentioned his experience with a 30 per cent. chromium cast iron, which was white and, therefore, had similar foundry characteristics to that used by the author. It had to be cast at a temperature of about 1,430 deg., as estimated by the Schofield pyrometer. He had experienced the same trouble as had the author, that although the synthetic sand could be rammed harder than the naturally-bonded sand and the gases would still get away, the result was some cracked and pulled castings. It was not necessary, for making the small castings, to have green strength of 5 to 7 lbs. per sq. in.; one could make them with green strengths of about $2\frac{1}{2}$ lbs. per sq. in. and save the bentonite.

Referring to a series of tests he had carried out with the A.F.A. tester, with a single vent to within $\frac{1}{4}$-in. of the face of the test piece, he said that in a mixture of the Mansfield variety, which had a permeability of 18 to 22, with one vent in the 2 in. circle it went up to 25; in the case of a synthetic sand having an A.F.A. number of about 100 to 120, it went up to 150 with a single vent. The fact that the moulds were rammed very much harder in the one case than in the other had had an effect on the strength, but not very much influence on the permeability as shown by the A.F.A. test. It was rather an important point that the effect of the permeability over an area was the same in the synthetic sand unvented and even rammed hard as in a natural sand which had to be vented and rammed fairly soft; there was the same ease of evacuation of gases, or indeed, the evacuation was easier, in the case of the synthetic sand.

Mr. E. H. Brown, referring to the problem of accuracy of dimensions, said he was afraid it was not sufficiently realised generally outside the malleable industry how great were its difficulties as compared with those of other branches of the founding industry. Reference was made in the Paper to three factors which tied up with that. Casting temperature was one; founders in general did not seem to appreciate the differences which the initial casting temperature would make when working to the extreme accuracy of dimensions demanded nowadays for repetition production. Chills had a definite effect; and, even more important, there was the problem of the location of the feeding heads. Although Mr. Webster had referred to the smaller firms as the "back yard foundries," Mr. Brown felt, in view of the large quantities of jobbing malleable castings being made today, that those firms should be referred to almost as the backbone of the industry. He urged that they deserved a lot more assistance than they received on the problem of the location of feeders; in many cases not sufficient assistance had been given by the users to the actual makers of the products.

Far too little inspection was carried out at the average foundry; and even where there was inspection, it was not done by foundry experts. There was very definite need for improvement in that direction. Finally, with regard to core location, in many foundries he had seen the cores being located very accurately by jigs, but in his view still insufficient use was made of jigs and gauges in the actual setting of the cores in the mould; consequently, troubles occurred.

Author's Reply

Mr. Roxburgh, in replying to the discussion, thanked Mr. Webster for his remarks, and said that he was indebted to Mr. Shepherd for having answered Mr. Webster's criticism of the current specification for malleable iron castings and for having brought to the latter's notice the work of the Institute of British Foundrymen and the British Cast Iron Research Association in this connection.

Mr. Roxburgh assured Mr. Shepherd that he appreciated his complimentary remarks concerning the Paper, and took the opportunity of paying tribute to Mr. Shepherd for his valuable contribution to the discussion. Mr. Shepherd's brief review of the position, status and future of the malleable industry had been most interesting. Mr. Shepherd had referred to chills and had mentioned his experience of coating them with shellac and dusting them with fine sand. Mr. Roxburgh said that, although he had not tried this method, he would certainly do so. With the coating he himself used, the oil on the surface of the chill definitely assisted in keeping it in a dry condition, which was an important consideration. As to the formation of primary graphite due to scale or oxide on the chill, Mr. Roxburgh said that he would not use a chill in that condition, but would endeavour to clean it, if possible, by sand-blasting. Failing that, he preferred to replace a chill rather than take risks by its extended use. Regarding the type of bentonite he had used in his initial work with synthetic sand, Mr. Roxburgh indicated that it was a western bentonite. As a matter of interest, he said that recently he had found that the No. 3 Fulbond compound had given even better results than the No. 1 material.

The author, after expressing appreciation of Mr. Shotton's contribution, agreed that the density of ramming had as much effect on the occurrence of "pulls" in castings as had the lower moisture content of the synthetic sand, and mentioned that a great deal of attention had had to be paid to this aspect. With regard to the increase of permeability shown by the backing sand, after continued use, Mr. Roxburgh could only suggest that the strength of the sand had been reduced by the diminution of bond, and also the percentage of coal dust had become less and that these two factors were contributory to this end. Mr. Shotton had referred to the manufacture of the tank hub casting, and he agreed that it was perhaps surprising to find that the top of the flange was sound when joint feeders alone were used. It was quite correct to state that the casting temperature was most important, and that it was necessary to cast at as low a temperature as possible. There was merely a run-off on the top of the flange, and, as a matter of fact, thousands of castings had been made in this manner, and he could guarantee that they were quite sound. Mr. Shotton's opinion in regard to atmospheric pressure feeding as applied to malleable castings had been noted and, although Mr. Roxburgh's experiments in this direction were only in the initial stages, yet, so far, he could only agree.

He had been very interested to hear of Mr. Tucker's experiences with synthetic sand. He had noted particularly the suggestion that, with small castings, the green sand strength could be considerably reduced, and his comments regarding the comparison of the effect of permeability over an area between synthetic sands and natural-bonded sands were of great interest.

Replying to Mr. McRae Smith's question concerning the running of metal direct into the top spherical feeders, Mr. Roxburgh said that, invariably, this was his practice with joint feeders, and, in the Paper, he had mentioned the superiority of "running-feeders" over "off-feeders." He did not, however, run metal into top feeders because he was concerned only with green-sand moulding, and would be afraid that the dropping metal would damage the mould and also affect the actual running of the casting. Nevertheless, it was good practice to fill the top feeder partially, and then make an addition of hot metal to increase the effectiveness of the feeding metal.

He agreed with Mr. Brown that the accuracy of dimensions with malleable castings was a problem, and that the variables which exerted an influence on this matter required particular control. He mentioned that he had stressed particularly in the Paper the importance of first-class tackle and also of inspection. He said that every casting manufactured in his foundry was inspected and, in the Paper, had given illustrations of core gauges used in the coreshops and also gauges for the moulders in the foundries in order to ensure the accuracy required.

WRITTEN DISCUSSION

Patching Synthetic Moulds

MR. J. L. FRANCIS wrote asking the two following questions:—(1) When using synthetic moulding sand, had the author experienced any difficulty in the mending up of moulds done by hand? Machine moulding was a different proposition, because the time taken to ram up and draw the pattern was not very long; moreover, the pattern was drawn by the machine. With hand moulding, the time taken in ramming was longer, and drawing of the pattern often necessitated some patching up of the mould. It has been personal experience that lower moisture content of synthetic sand, combined with the longer time taken to prepare a mould by hand, resulted in drying out of the sand, so that mending up was rendered very difficult, especially on the larger and intricate work, where time taken in ramming and mending up might be considerable. Furthermore, it would be interesting to know whether the moulders who asked for synthetic sand in preference to the natural bonded sand were doing machine or hand moulded work.

(2) Did the author use any dressing on his cores? Presumably he used none on the moulds, since they were cast green and coal dust was incorporated in the sand.

MR. ROXBURGH pointed out that all the moulding carried out in his foundry was with green sand and that synthetic sand had only been used for machine moulding. Probably Mr. Francis would agree that it was not an economical proposition to patch a mould produced from a moulding machine, and that it was cheaper to knock the mould out and make another. He agreed that, with hand moulding, patching-up did present difficulties and was usually effected by wetting the damaged part of the mould and by subsequent sprigging. In order to avoid or reduce the drying out of synthetic sand, it was customary to add a small percentage of oil, which had been found advantageous.

In the main, no dressing was used on any of the cores, except in some special cases where it had been found necessary to black them with a mixture of wet blacking and plumbago. For example, the cores used in the manufacture of the 3-in. bombs, illustrated in the Paper, were treated in this manner. There was, however, no dressing used on the moulds, as they were cast green, the sand incorporating coal dust.

Paper No. 771

The Spectrographic Analysis of Cast Iron

By F. B. LING*, J. McPHEAT* (Associate Member) and J. ARNOTT* (Member)

The industrial spectrograph finds its greatest application in the routine analysis of steels, aluminium alloys and brasses. The equipment at Cathcart was not purchased primarily for any one of these uses, but as a general purpose tool, with the expectation that it would serve for some difficult estimations in nickel alloys. It might be added that several of the latter have since been handled with satisfactory results. Shortly after the spectrograph was installed, it was considered that it would help to build up general experience if the method could be used for a period on samples which were being analysed daily by chemical means. At the time the most readily available were cast irons.

The most of the work was done some considerable time ago, but the original programme was not completed because some more immediately urgent work had to be undertaken. In recent months several firms have become interested in the subject, and since little work on cast iron appears to have been done, or at any rate published, in this country, the authors felt that it might be of some small service to give the results obtained, even though the range of alloying elements is rather narrow.

General Description

It is probable that the whole matter may be new to some of the members; hence it might be useful to give a very brief description of the apparatus and the method of use.

The industrial spectrograph covers a wave band of 2,000 to 8,000 A.* Alloys of the ferrous group give a spectrum containing so many lines that maximum dispersion is essential; hence the largest size instrument is necessary. The work to be described was done on a large-size Hilger quartz spectrograph. In this instrument, the band of 2,000 to 8,000 A. would give a spectrum of 30 in. long. A photographic plate of this length is impracticable, and the instrument is therefore so designed that the complete spectrum can be photographed in three sections of 10 in. Any 10 in. of the 30 in. can be utilised; throughout this investigation a band of 2,700 to 4,300 A. was used.

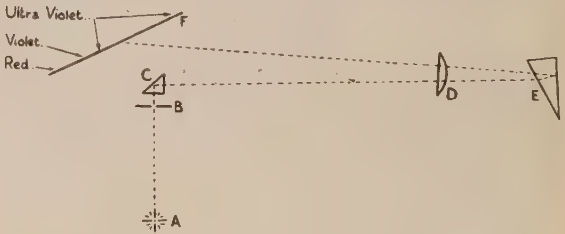

FIG. 1.—LARGE QUARTZ SPECTROGRAPH, OPTICAL TRAIN.

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* The authors are respectively, Spectroscopist, Senior Analyst and Chief Metallurgist, G. & J. Weir, Limited. Mr. McPheat and Mr. Arnott were awarded Diplomas for this Paper.

* A = Angström Unit = 10^{-8} cm,

The essential features of the spectrograph itself are shown in Fig. 1. The light from the sample (A) is passed through the slit (B) and is reflected by the right-angled prism (C) to the collimating lens (D). It is then reflected by a 30-deg. Littrow prism (E). The back of this prism is a mirror which reflects the light back through the collimator. The latter now acts as a camera lens to the photographic plate (F). It will be readily understood that since the work is in the ultra-violet region the lenses and prisms must be made of quartz.

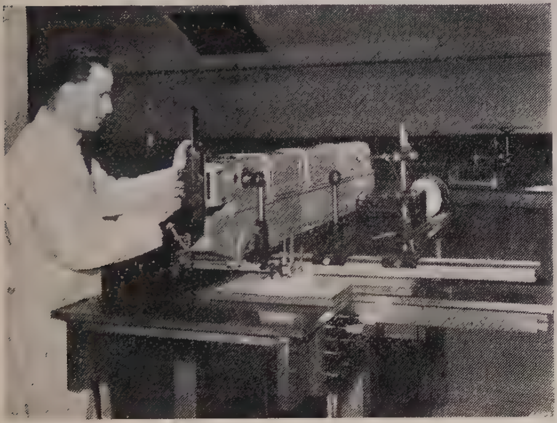

Fig. 2.—Exposure of Plate.

Slit Width.—The function of the slit is to control the width of the lines which appear on the spectra; in the authors' work a slit of fixed width, 0.015 mm. is employed.

Excitation.—The light is produced by a high tension discharge between the sample and a graphite electrode.

Plate.—The plate used is 10 in. by 4 in., and the type of emulsion is not widely different from that used in ordinary photography. Many spectra can be taken on one plate because they need only be a few millimetres in height. In the work to be described, a slit height of 2.5 mm. was employed throughout. This allows up to 24 separate exposures to be taken on one plate.

Operation of Spectrograph

The manipulative side of the whole method is best shown by the three photographs in Figs. 2, 3 and 4. Fig. 2 shows the exposure of the plate; the spark seen at the right-hand side is being produced by a H.T. discharge between the sample which is below and the graphite electrode above. Fig. 3 indicates how the visual comparison and recognition of the line is made in the "Judd-Lewis" comparator. In this instrument any plate can be easily compared with a standard plate bearing spectra from alloys containing all the elements under consideration, or even from composites of the various pure metals or ferro-alloys in the powdered state. The standard plate is not used quantitatively; it is only utilised to spot the important lines of the elements. Fig. 4 illustrates the measurement of line intensities in the micro-photometer.

The spectrograph requires solid specimens (not borings), and these may be of any reasonable size and shape, but preferably about 1 cub. in. A piece of 1.2 in. dia. test-bar is ideal.

Quantitative Estimation

In very simple language, the mechanism of quantitative estimation by means of the spectrograph is as follows:—The spectrograph splits up composite light from the spark, giving series of lines on the photographic plate. Each element present gives lines of definite and known wavelengths. By reference to wavelength maps it can be quickly determined if any one element is present.

It has been found by earlier workers that the percentage of any one element, say manganese in cast iron, is determinable by the internal comparison method. This is simply the measurement of the blackness of any one line of the element compared with that of a chosen line of the major element within the same spectrum. In cast iron the major element is, of course, iron. It may come as a surprise to some that most elements give many lines. Iron is profuse in this respect, giving about 10,000 lines within the range of this spectrograph.

The first step towards quantitative spectrographic analysis is the careful preparation and chemical analysis of a series of samples, say six in number, covering the complete range of the element or elements to be determined spectrographically. The chemical analyses of these samples must be of the highest possible accuracy, since the value of the spectrographic estimation is completely dependent on this.

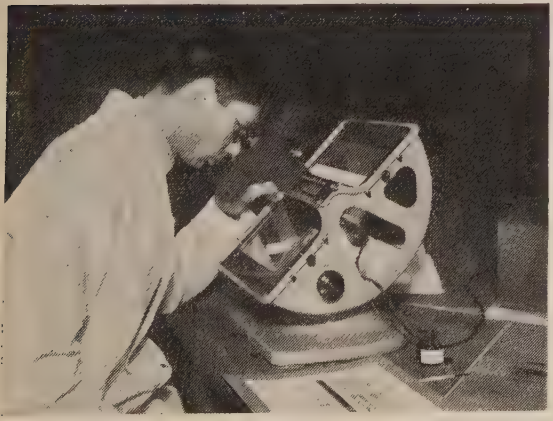

Fig. 3.—"Judd-Lewis" Comparator.

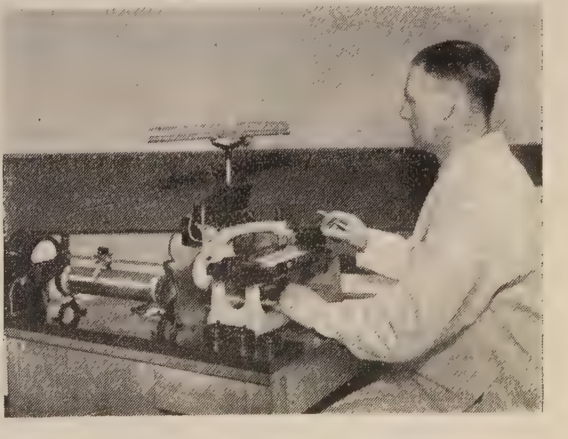

Fig. 4.—Micro-photometer.

A plate is exposed with the standards on it, probably in triplicate, and the intensities of the "line pairs" measured. This term is applied to the chosen lines of the minor and major elements. The ratio, or more generally the log ratio, of these intensities is plotted against the percentage of the element, and the curve so obtained is utilised for all future samples.

It will be appreciated that all factors connected with the exposure, the plate itself and the details of development must be rigidly standardised. Many and possibly most of the discrepancies encountered are due to neglect to observe all the conditions and precautions.

Of the constituents present in cast iron, carbon, phosphorus and sulphur cannot be estimated by the methods described in this Paper. Silicon, nickel, manganese, chromium and molybdenum have been estimated within certain ranges, and there is every reason to expect, from analogy with steel manipulation, that vanadium, titanium, aluminium and traces of other accidental elements can be tackled.

TABLE I.—*First Set of Standards.*

Mark.	Si. Per cent.	Mn. Per cent.	Ni. Per cent.	Cr. Per cent.	Mo. Per cent.
2	1·00	0·51	—	—	—
4	0·68	0·31	0·28	0·21	0·37
5	1·28	0·62	0·43	0·42	0·38
6	1·51	0·79	0·73	0·51	0·70
7	1·68	1·01	1·10	1·05	1·04
8	1·90	1·14	1·13	1·14	1·18
9	2·32	1·30	1·45	1·06	1·37

The technique for the first set of trials was on the lines of that used for steels by the Admiralty Laboratory in Glasgow University. The conditions were as follows:—

Wave band ...	2,700-4,300 A.
Slit width	0.015 mm. (fixed slit)
Spark gap ...	3 mm.

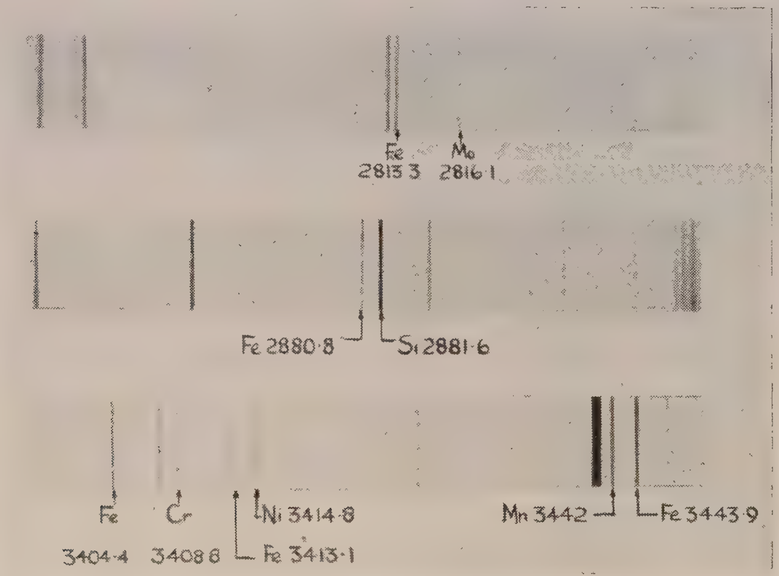

FIG. 5.—LINE PAIRS FOR ALLOY CAST IRON.

Before going on to describe the experimental work it should be mentioned that the authors took as their text-book throughout Mr. Barker's Paper to the Iron and Steel Institute in 1939.

First Trials

No irons were available of compositions covering the range desired, and it was necessary to make up a suitable series. Details of the first set of standards to be prepared are given in Table I. These were all made in crucibles from the same mixture by addition of the alloying elements. The total carbon, phosphorus and sulphur were practically constant throughout at 3.3 per cent., 0.35 per cent. and 0.11 per cent. respectively.

The chemical figures were the mean of results from four analysts. The samples were cast in core sand, 1.2 in. diameter, 6 in. long after discarding the head. Each sample was cut in half. One portion was drilled down the centre for its entire length and the drillings thoroughly mixed for analysis, the other half of each was reserved for the spectrograph.

Voltage	15,000 volts.
Added inductance....	Nil.
Upper electrode ...	H.S. graphite pointed to 80° angle.
Lower electrode ...	Sample, filed flat on sparking face.
Exposure	90 secs., made up of six separate exposures of 15 secs. across face of sample, top electrode changed after three exposures.
Plate	Ilford thin film half tone.
Development ...	(*a*) 90 secs. at 19.5 deg. C., using 100 cc. standardised developer. (*b*) Fixed in acid hypo for 7 min. (*c*) Washed—running water for 15 min. (*d*) Dried—warm air from hair drier.

This gave somewhat under-exposed plates, which were not suitable for measurement.

The next set were run with:—

Exposure	2 min., made up of four separate exposures of 30 secs. each. Graphite electrode changed every 30 secs. exposure.
Development ...	2½ min. in 100 cc. standardised developer at 19.5 deg. C.

All the other conditions were similar to the first. The standard samples were exposed in duplicate (plate F.21), and from this plate a set of curves was prepared, using the following line pairs:—

Silicon	2,881.6 A. with iron 2,880.8 A.
Manganese ...	3,442.0 A. with iron 3,443.9 A.
Nickel	3,414.8 A. with iron 3,413.1 A.
Chromium ...	3,408.8 A. with iron 3,404.4 A.
Molybdenum ...	2,816.1 A. with iron 2,813.3 A.

The significance of line pairs can be better appreciated by reference to Fig. 5, which is a series of enlargements of portions of an alloy cast-iron spectrum. The curves are reproduced in Fig. 6. These curves were mainly good, and they were used for a period to check routine samples which were analysed chemically. Over this period agreement was tolerable, but a few eccentric figures for manganese called for further work.

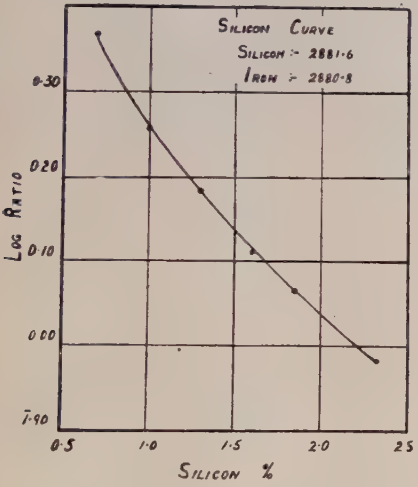

Fig. 6a.—Silicon Curve.

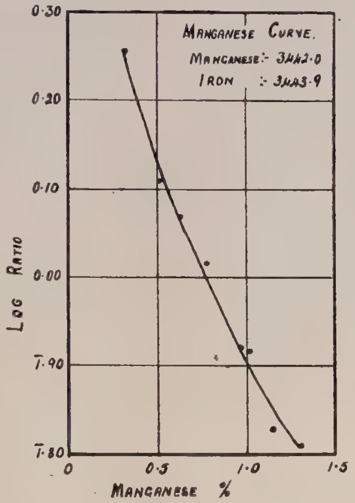

Fig. 6b.—Manganese Curve.

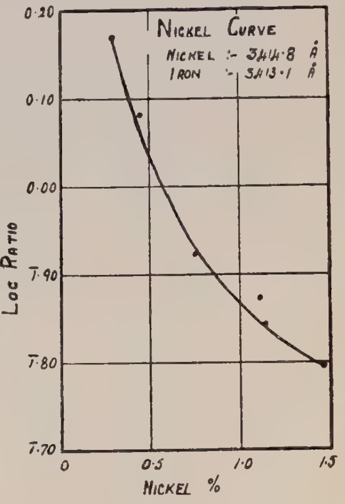

Fig. 6c.—Nickel Curve.

At this stage, the original batch of plates was exhausted. New curves were drawn for the next batch of the same type, and it was found that the new curves were so similar to the original that no serious error would have been caused by using the old curves for the new plates.

Second Set of Standards

After some further work it was realised that the composition of the first series of standards had not been well chosen. Some were difficult to drill for chemical analysis, and furthermore the progressive increase in all the added elements resulted in considerable differences in the iron content. These, it was thought, might affect the density of the lines of the major element. It was resolved to make a new series and to limit the range to that required for the routine examination of samples as then received from the foundry. Details of the second set of standard samples prepared are given in Table II.

Table II.—*Second Set of Standards.*

Mark.	Si. Per cent.	Mn. Per cent.	Ni. Per cent.
A.1	0·95	0·48	1·72
A.2	1·15	0·69	1·03
A.3	1·37	0·81	1·13
A.4	1·65	0·94	0·60
A 5	1·94	1·03	0·30

In the second set of standards, Cr and Mo were not included because iron with these elements was seldom received in the laboratory, and also because the original curves from plate F.21 were so satisfactory that new curves could be readily made at any time, using the same line pairs, if the need arose.

At this time, Zenith H. & D. 700 plates were being used for arc spectra of non-ferrous alloys, and since the number of routine cast-iron samples was small, it was decided to see if a compromise could be effected to save plates and processing time. Ilford ordinary plates were chosen, and this choice was endorsed by work done by Hilger, Limited, on some samples of cast iron which had been sent for manganese estimation. Hilger, Limited, obtained very good results, using Ilford ordinary plates. The conditions they used were:—

Wave band ...	2,700-4,300 A.
Slit width	0.015 mm.
Spark gap ...	3 mm.
Voltage	15,000 volts.
Added inductance....	Nil.
Upper electrode ...	H.S. graphite pointed 80° angle.
Lower electrode ...	Sample filed flat.
Exposure	Single spark, 30 secs.
Plate	Ilford ordinary.
Development ...	2 min. at 19.5 deg. C.

The standard samples were exposed in triplicate under these conditions. The plate was measured for silicon, manganese and nickel, using the same line pairs as formerly. While the silicon and nickel curves were very promising, the manganese results were bad and no consistency could be observed. The silicon curve was used for checking some routine samples, but agreement was not very good; the difference amounted to as much as 0.10 per cent. silicon in samples containing about 1.5 per cent.

From the outset it had been recognised that the silicon estimation was one which would present the greatest difficulty. Unfortunately, silicon has only one line (2,881 A.), in the portion of the spectrum generally used for iron and steel analyses. This line is so strong that it is used for the estimation of silicon in steel down to percentages of the order of 0.02 per cent. At figures of 1 to 3 per cent., therefore, it is a very intense line, and the problem resolves itself into one of obtaining a silicon line of penetrable density, with exposures which will give adequate density in the lines of other elements down to the low limit of their possible presence.

After this, it was decided to investigate pre-sparking for a period of ten seconds before the exposure of thirty seconds, with all the other conditions the same as those mentioned above. A plate was taken and measured for silicon and manganese (F.81). The pre-sparking period had clearly benefited the manganese result, while the silicon line was also fairly satisfactory. After consideration of the various points brought out by this trial, it was decided to reduce the exposure time and also to increase the pre-sparking time. It was hoped that the intensity of the silicon line would be decreased and that further improvement in the manganese line might result. This was done with the following altered conditions:—

Pre-spark	...	15 secs.
Exposure	...	25 secs. (single spark)
Plate	...	Ordinary;

all other conditions as before.

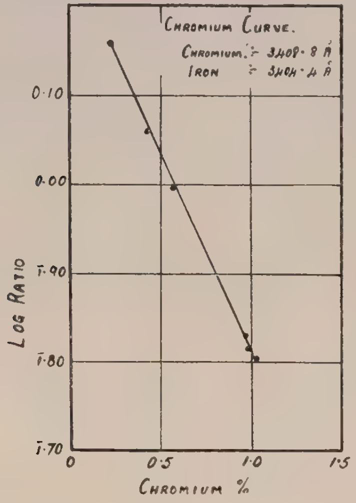

FIG. 6D.—CHROMIUM CURVE.

This plate gave promising results for silicon, manganese and nickel. The manganese showed increased reproducibility. After consideration of the graphs it was thought that the one for silicon might be improved by trying some other iron line for comparison. This silicon graph showed an almost straight line between 1.0 and 1.4 per cent. silicon. Thereafter, it developed a curve between 1.4 and 2.0 per cent. silicon. Further, the point at which the silicon and iron lines were equal in intensity was too far removed from the part of the graph covering most of the work. With these matters in view, various other iron lines were measured against the usual silicon line, but it was found that the shape of the curve was practically independent of the iron line. The only thing left, therefore, was to experiment further with the conditions, and a series of exposures was made with changes in the added inductance of the spark circuit. It was found that 0.06 mH, which was the lowest amount available, gave the most promising figures. A set of standards was then exposed under the following conditions:—

Spark gap	...	3 mm.
Added inductance		0.06 mH.
Pre-spark	...	10 secs.
Exposure	...	40 secs. (single spark)
Plate	...	Ordinary;

all other conditions as before.

This plate was measured for silicon, manganese and nickel. Good log ratios were obtained, agreement being within 0.010 of the average. The graphs prepared from this plate gave smooth curves. The silicon curve was used to check routine samples over a short period.

When the results were reviewed, it was found that roughly 40 per cent. showed a disagreement between chemical and spectro of over 4 per cent., and it seemed probable that there had been some want of care in some of the smaller details. On investigation of the alignment of the light source, it was established that errors up to ± 0.08 per cent. silicon were possible through incorrect alignment of the electrodes in both the horizontal and vertical planes.

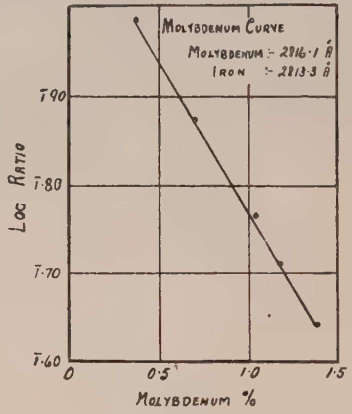

FIG. 6E.—MOLYBDENUM CURVE.

The other sources of error were connected with the temperature and quantity of developer. It was found that the volume of developer had an effect on the density of the plate; hence any accidental spilling would alter the density. This effect was lessened by increasing the volume of developer used.

It was realised that insufficient attention had been paid to temperature. The dark room temperature was frequently higher than 20 deg. C. and a rise of 1 deg. C. of the developer was possible during the time of development. From this investigation it was decided to standardise development in future to 150-c.c. developer and 20 deg. C., using a thermometer reading to 0.1 deg. C.

Final Conditions

As a result of many experiments, the best conditions were found to be as follow (Plate F.101):—

Wave band ...	2,700 to 4,300 A.
Slit width	0.015 mm. (fixed slit).
Spark gap	3 mm.
Voltage	15,000 volts.
Added inductance	0.06 mH.
Upper electrode ...	H.S. graphite sharpened to 80° angle.
Lower electrode ...	Cast-iron sample—flat face.
Pre-spark	10 secs.
Exposure	30 secs. (single spark)
Plate	Ilford ordinary.
Development: ...	(1) Standardised developer, 150 c.c. for 2 min. at 20 deg. C. (2) Fixed acid hypo for 7 min. (3) Washed—running water, 15 min. (4) Dried in current of warm air.

Plate F.101, taken under these conditions gave the curves illustrated in Fig. 7. The curves were all satisfactory and in later work no further change in conditions was found necessary. Subsequent exposures of routine samples and the standards under these conditions gave results which agreed within the usual analytical tolerance with the chemical figures.

Assessment of Utility

The place of spectrographic work in cast-iron analyses must in all cases be affected by the type of iron to be tested, the number of samples to be handled, the need or otherwise for speed, and the specific alloying elements to be estimated.

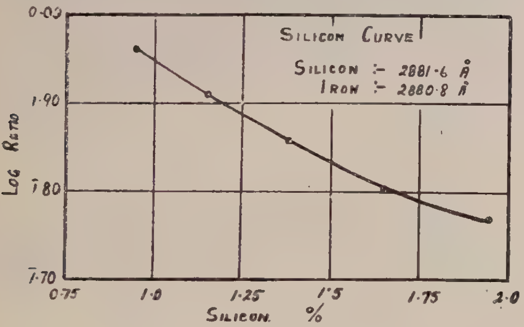

FIG. 7A.—SILICON CURVE.

Then this investigation was commenced, spectrographic analysis was the only alternative to purely chemical methods. Since then, however, the Spekker Absorptiometer has come into prominence, and it undoubtedly provides excellent methods for the estimation of elements which directly or indirectly give coloured solutions. The estimation of manganese, for example, is delightfully speedy and accurate. It can be safely assumed that both spectrographic and absorptiometric methods will be intensely developed in the near future and any attempt at appraisal of their relative suitability can only be taken as applying to to-day's date.

Advantages and Limitations of Spectrographic Analysis

The advantages of spectrographic methods as applied to cast iron might be stated as:—

(1) *Speed and Reduction of Labour.*—Once the conditions are established, routine samples can be run through quickly, taking spectrograms of, say, a dozen samples in duplicate on each plate. Each sample may contain five elements which are to be estimated. The preparation, exposure, development, etc., are the same no matter how many elements are to be estimated; the only difference is the few additional minutes at the microphotometer.

As a rough idea of the overall time involved, a single operator averaged 2½ hrs. for nine samples of cast iron. In these silicon, manganese and nickel were estimated in duplicate. This gives a time for each duplicate estimation of under six minutes. This was done without any attempt to cut the time to the minimum, and the allocations for some of the operations were very generous. With two operators the time can be very much reduced. Apart from capital costs, the only outlay is that for plates and developer. With twelve samples on a plate, the cost per sample is under 2d.

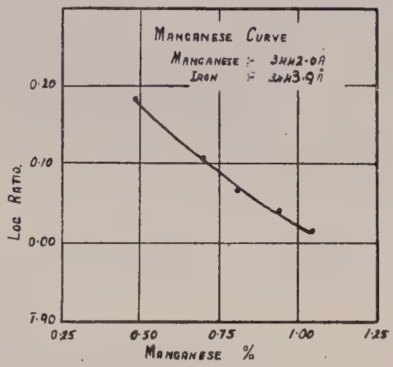

FIG. 7B.—MANGANESE CURVE.

(2) *Sample Easily Prepared.*—There is no need to drill; hence the hardness of the sample does not matter.

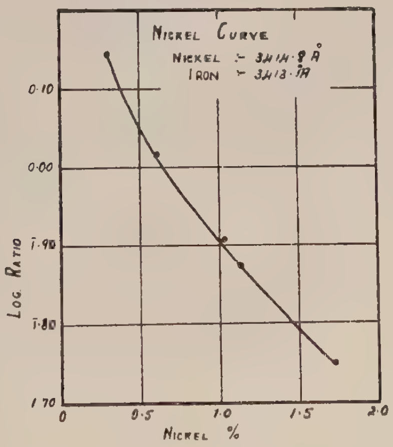

FIG. 7C.—NICKEL CURVE.

(3) *A Permanent Record is Obtained.*—At any time, a plate may be looked out and measured for some element not originally checked.

The disadvantages or limitations cover the following:—

(1) The method can only be applied to the estimation of elements whose log-ratio curves have been determined. For maximum accuracy, the curves should have been determined from standards of roughly the same type as those to be examined.

(2) There is a distinct top limit to the amount of an element which can be determined. These limits have not been explored, but it is doubtful if silicon in excess of 3 per cent. can be estimated with reasonable accuracy.

(3) The area which is sparked is so small that unsatisfactory results are obtained from non-homogeneous samples. If the homogeneity of the samples is in doubt, recourse must be made to the composite spark method.

(4) The method, as at present practised, is not applicable to drillings.

The authors wish to record their appreciation of the help received from Mr. Barker, of the Bragg Laboratory, and from Messrs. Cross and Goodall, of the Admiralty staff. In conclusion, the authors' thanks are due to the directors of Messrs. G. & J. Weir, Limited, Cathcart, for their interest and encouragement in the work and for permission to publish this Paper.

DISCUSSION

DR. A. B. EVEREST recalled a visit he made about six years ago to a very well-known firm in America; a number of castings were made there in Ford alloy, and their practice was particularly interesting, as it depended on spectrographic control. A ladleful of cupola metal was transferred to a converter and blown to steel. A second ladle of the same cupola metal was then taken and poured together with the freshly-made steel into an electric furnace, where it was refined and alloyed. Thus, they produced a true steel mix iron running about 1.25 to 1.5 per cent. carbon. When refining and alloying were nearly complete, a pencil of the metal was cast and was taken to the spectrographic laboratory, where the essential elements were determined spectrographically in a few minutes. During that time the bath was held: afterwards the metal was adjusted as necessary and was cast. The spectrographic method appeared to be ideal for control of this type where one was casting a very large number of heats in one particular metal; he felt, however, more dubious whether it was generally applicable to jobbing analyses. The British Cast Iron Research Association and other organisations, he said, were interested in applying the spectrogram; but he was sceptical as to whether it was a reliable instrument for analysing different types of irons. He would like to know if it could be used for the analysis consecutively of a highly alloyed iron of, say, the Ni-Resist type, then a pig-iron, then an engineering casting.

With regard to the arc or spark which was struck in order to obtain the spectrograph, he had been under the impression that an arc was used in the firm he visited, this being struck between two pieces of the same metal. The authors of the Paper, however, referred to a high-voltage discharge between a carbon pencil and a block of the metal which was being examined. Was it really an arc, or was it something else?

Limitations Imposed

MR. ARNOTT replied that the spectrograph could not be applied as a general all-round instrument to all ranges of irons, since one iron was highly alloyed and another was not. At the same time, the spectrographic method was the best qualitative analysis method possible, showing which elements were present. Although the basis work done by the user might not be such as to give exact quantitative results for any sample, it would very often give the results closely enough.

MR. MCPHEAT, replying to the question concerning the arc and spark, said the arc was one of the first methods used for spectrographic analysis, and it was still a very good method; but it had not the same accuracy as the spark. For example, the arc would give an accuracy of about from ± 5 to ± 8 per cent. of the element present; the spark gave an accuracy very much closer, say, ± 3 per cent., particularly in low concentrations. One Paper claimed an accuracy of ± 5 per cent. of the elements present in 18 per cent. of chromium steel.

The arc uses d.c. of low voltage with a current of, say, 2 to 5 amps. As a result, a considerable area of the specimen is heated. The spark method operates with a 15,000-volt discharge at very low amperage, and produces much more localised heating of the sample.

Arc and spark lines differ in their characteristics; arc lines are very good for qualitative recognition, but have not the same constant intensity of spark lines.

Narrower Plates Suggested

A MEMBER said that the spectrographic method had distinct possibilities in the laboratory; he could appreciate also that in a foundry it would be very useful for the segregation of scrap or the examination of castings which were already made and in respect of which there was no urgency, but he suggested that it would be necessary to reduce the size of plate before it would be adopted for control purposes in medium-sized foundries, which would require only about a dozen estimations a day, and would normally want the results quickly. With the normal type of apparatus a number of estimations had to be made in order to ensure accurate results; he suggested that the instrument makers might be asked to make the plates of narrower cross-section, which would render the spectrographic method more economical and more rapid.

Most foundrymen, he supposed, would be more willing to consider methods which would give results whilst the metal was still in the ladle. Ladle additions were being made, and crude foundry tests had been developed which would give an idea of the properties of the metal before casting. With the spectrographic method it might be possible to make an estimation of the metal in a ladle within six minutes; any ladle of 2 or 3 tons capacity could be held for 6 min. before casting, so that there were possibilities in that direction. Of course, matters such as segregations and the possibilities of surface contamination would have to be carefully worked out. Further, spectrographic analysis was not a job that could be allotted to other than skilled people.

The Time Factor

MR. F. DUNLEAVY wished to compliment the authors upon a very interesting and unusual method of analysis. Often a great deal of trouble and irritation was caused by pouring moulds with unsuitable irons. Evidently the authors had eliminated any doubt in regard to the analysis of the metal in the ladle, and thereby enabled the foundryman to know before pouring that the metal was correct. The analysis was of less value three or four days after casting, when the foundryman could have quite a heap of scrap behind him. Any method that will assist in cutting down scrap, thereby saving man-hours in foundry, machine shop, etc., would be universally appreciated. He felt sure that the methods used by Mr. Arnott and his colleagues would be used in the near future far more extensively throughout the foundry world than they appeared to be at the moment.

Organisation Imposed

MR. ARNOTT replied that obviously the time factor was important. He and his colleagues had not to operate on quantities. It was quite true that a plate could be exposed, developed and interpreted in six or perhaps eight minutes; but that represented the best practice, involving the services of three operators, assisted by every mechanical aid available. They had to get a specimen, cool it, cut it and prepare a good surface, spark, develop the plate, wash it and dry it, put it on the microphotometer, take the readings for each element and consult the chart; obviously, to do that in six minutes involved extremely good individual and team work; yet it had been done.

With regard to effecting economies, it might be possible to reduce the size of the plate. In ordinary work, where the time element is not important, a large number of specimens could be dealt with on one plate, so that it was quite economical. But if there were a big demand for the apparatus for use in making rapid estimations, he imagined that the manufacturers would in due course, though not just now, meet that demand. The method had enormous possibilities, and anyone who had seen the Bragg Laboratory would realise that it had opened up a new field. It was only recently, and especially since Barker's work, that the very steep industrial development had been made possible.

WRITTEN DISCUSSION

MR. J. G. PEARCE wrote congratulating the authors of this Paper very warmly, both on the work they have done and on the fact of its publication. They were among the pioneers of spectrographic work on cast iron, probably one of the most difficult materials to which the method could be applied. Their comments on the following points would be appreciated.

Homogeneity was very important in the examination of cast iron. According to Barker, the sparking crater was about 1 mm. dia. With materials containing considerable amounts of phosphide eutectic or in which other segregates were likely to be present, the examination of one place only might lead to incorrect results. The examination of a point, for example, at which there might be a local concentration of phosphorus due to phosphide eutectic, would affect the determination of other elements, apart from the fact that the other elements would probably not be associated at this point in the same proportions as in the metal as a whole. The authors note that if homogeneity was in doubt, recourse must be had to the composite spark method, and it would be interesting to know their experience on this point. In the United States, they appeared to use an air-blast across the spark and hemispherically ended electrodes. Have the authors any information on the effect of different electrode shapes? In recent months the quality of photographic plates for photomicrographic work had deteriorated, and if the same lack of uniformity was present in spectrographic plates, much work will be involved in drawing new curves. Could the authors give an indication of the ranges of composition which could be determined for the various elements, providing an accuracy comparable with ordinary wet methods of analysis?

Authors' Reply

The AUTHORS, in reply, wrote that they were deeply indebted to Mr. Pearce for his comments and for raising several very relevant points. The authors did not experience any trouble which could be put down to segregation. The reasons for this were probably:—(*a*) The irons used had a moderately low phosphorus content, and (*b*) the craters were much larger than those obtained by Mr. Barker on steel samples. Mr. Barker gave a 10-sec. exposure, without added inductance, whereas the authors used finally a 30-sec. exposure (following a 10-sec. pre-spark), and 0.06 mH added inductance. The diameters of the craters on cast iron were approximately 6 mm. Without added inductance they were 2 mm. dia. The effect of added inductance on the size of the craters was remarked on by Mr. E. van Someren in the discussion on Mr. Barker's Paper.

Composite Spark.—This method was used in the earlier stages of the investigation, but was later discarded because there did not appear to be any need for it, and it added a little to the time involved, especially if the graphite electrode was changed between each of the fractional exposures.

Air Blast.—The authors had no direct experience of this. It was used very effectively by Dr. Convey in his work on the analysis of segregates.

Shape of Electrodes.—The authors had not tried hemispherically ended electrodes. They had observed, however, that under the conditions employed the pointed electrode loses its point in the first few seconds of sparking and becomes what is virtually a conical point with a very small hemispherical end. The change took place during the pre-sparking period.

Plate Quality.—The authors had seen reports indicating some falling-off in plate quality, but had not themselves experienced such to any appreciable extent.

Range of Composition.—Within the range covered in the experiments, *i.e.*, from about 0.3 per cent. to about 1.5 per cent. of each of the alloying elements, the spectrographic method gave results as accurate as those obtained by ordinary chemical analysis. By using other line pairs, and possibly with slight variation of the operating conditions, the ranges could, no doubt, be extended a little, both upwards and downwards. Silicon may be exceptional in this respect and the difficulties with this element had already been referred to.

A Marked Advance

DR. J. E. HURST wrote that he would like it to be recorded that the Paper by Mr. Arnott and his colleagues, as far as he was aware, was the first public information before a British technical body on the application of the spectrograph to the analysis of cast iron. For this reason it was a Paper of very great importance, and deserved the particular attention of those who were faced with the problems of routine analysis under present-day conditions.

The application of the spectrograph to the routine analysis of cast iron was, of course, not new, and various concerns both in America and Germany had installed such equipment and had it in operation for some time. The information available of their experience with this equipment was just very scanty, and he had one hope that this Paper would be the means of encouraging some of our American friends to supply details of their experiences with this work in connection with cast iron.

The increase in the requirements of routine analysis had been brought about very largely by the residual elements which require to be determined. The writer's firm at Darlaston were proposing to instal similar equipment to that described in the Paper to deal with routine analysis of refined pig-iron. He took this opportunity of publicly thanking Mr. Arnott and his colleagues for the help and assistance that they had given already in connection with this matter, as also did Mr. Barker, of the Bragg Laboratory.

The AUTHORS wrote that they were very indebted to Dr. Hurst for his remarks. There was no doubt that the mass experience which would be accumulated by firms like Dr. Hurst's would result in a speedy widening of the scope of spectrochemical methods.

Paper No. 772

Meeting the Raw Materials Supply Position in Grey Iron Foundries

A REPORT BY THE CAST IRON SUB-COMMITTEE OF THE TECHNICAL COMMITTEE

Constitution

The constitution of the Cast Iron Sub-Committee of the Technical Committee is as follows:—

P. A. Russell, B.Sc. (Convener), Dr. A. B. Everest (Secretary), S. Carter, E. B. Ellis, H. Forrest, G. L. Harbach, Dr. J. E. Hurst, A. Phillips, R. C. Tucker, M.A., T. R. Twigger, and H. J. V. Williams.

Introduction

In any casting the primary requirement is soundness and freedom from internal defects. This consideration stands in front of all other qualities, such as mechanical strength. One of the most significant elements in cast iron from the point of view of its influence on soundness is phosphorus; but to-day foundrymen are being asked to use increasing amounts of native high-phosphorus irons and to conserve low-phosphorus materials such as hematite, steel scrap, and refined iron. Whilst these materials have been available for all essential demands, the iron foundries, as a whole, have had to cut down consumption for all purposes where it cannot be proved that their use could not be reduced or eliminated. Phosphorus has also a marked influence on the mechanical properties of cast iron, generally lowering strength, and particularly in reducing impact resistance or toughness. The use of phosphoric pig or scrap tends, therefore, to increase the difficulties of the foundryman in meeting specifications. This Report has been drawn up in an attempt to assist foundrymen in maintaining quality of output while meeting the supply position by using lower-grade raw materials.

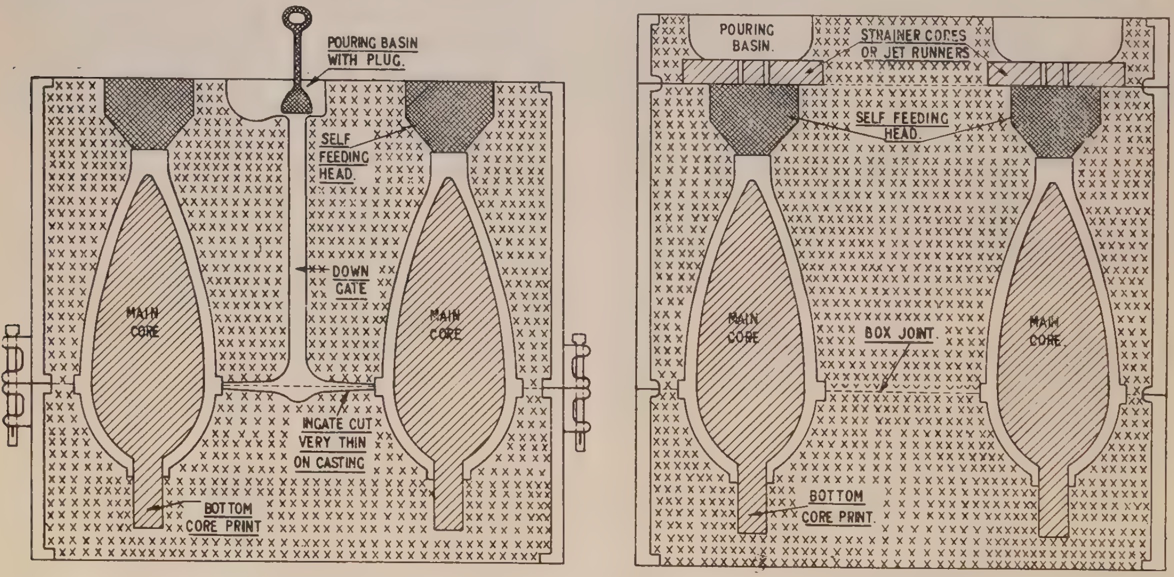

Fig. 1.—Methods of Casting Trench Mortar Bombs Vertically with Self-Feeding Heads.
(*a*) In 2-part moulding boxes with runner on joint. (*b*) With strainer or jet runners on top.

Apart from meeting the high mechanical strength specifications, low-phosphorus irons find a use as a means for ensuring soundness, particularly in castings which are subjected to pressure tests after machining. There are castings in which the mechanical strength requirements are low enough to permit of the use of native phosphoric irons, but for which low-phosphorus irons are used frequently in order that their freedom from porosity can be ensured.

Up to the present there is little evidence that the resulting products have suffered from curtailment of supplies, and foundries have, as a whole, adjusted themselves very satisfactorily to the altered conditions. Difficulties must have been encountered, and, in view of this, and the fact that more severe curtailment in supplies of hematite and steel scrap may have to be faced in future, the Sub-Committee feel that its members' experience may be of value to members of the Institute in general, who may be faced with problems similar to their own.

The Report is based on experiences to date in meeting the changed raw materials supply position, and includes a number of examples taken from practice. It concludes with suggestions for meeting conditions of further stringency in supplies.

Meeting the Position

The restrictions in low-phosphorus materials have largely been met by:

(*a*) Substitution of hematite by low-phosphorus blast-furnace pig-iron with P about 0.4 per cent., resulting in general increase in phosphorus. If the proportion of hematite in the charge did not exceed 30 per cent., the resulting increase in P was only 0.1 per cent., and this rarely caused any difficulty.

(*b*) Replacement of hematite by refined pig-iron. Low-phosphorus refined pig-iron is obtainable at a premium, and it has been possible to maintain castings at the same phosphorus level as before, while at the same time dispensing with the use of a certain amount of steel scrap. The use of very low-phosphorus refined pig-iron is discouraged, and a slight increase in phosphorus, as indicated in (*a*) above, can usually be tolerated.

(*c*) By careful control over the metal mixture, and especially over carbon and silicon contents whereby the deleterious effects of phosphorus on mechanical properties may be eliminated or counterbalanced. The use of late silicon additions is strongly recommended.

(*d*) By giving careful attention to improved methods of running and rising, *e.g.*, by the increased use of feeding heads, by the adoption of new running methods incorporating "atmospheric feeding" and special types of feeder gates.

(*e*) By adopting centrifugal casting methods wherever practicable.

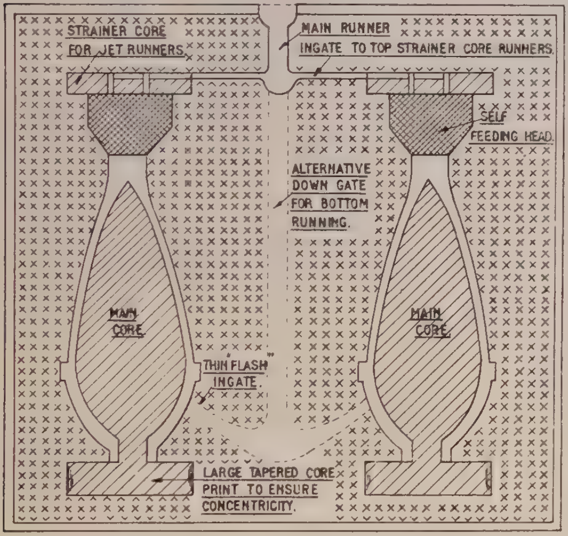
STRAINER CORE FOR JET RUNNERS
MAIN RUNNER INGATE TO TOP STRAINER CORE RUNNERS
SELF FEEDING HEAD
ALTERNATIVE DOWN GATE FOR BOTTOM RUNNING
MAIN CORE
MAIN CORE
THIN FLASH INGATE
LARGE TAPERED CORE PRINT TO ENSURE CONCENTRICITY

FIG. 2.—DIAGRAMMATIC SKETCH OF "DRAG" HALF OF MOULD SHOWING CORE IN POSITION, ALSO SUGGESTIONS FOR TOP AND BOTTOM RUNNING WITH FEEDER HEAD. MOULD IS PRODUCED FROM SPLIT PATTERN AND TURNED ON END TO CAST.

(*f*) By careful attention to pouring temperature.

(*g*) By the correct use of denseners.

In elaboration of these points the following details and examples supplied by members of the Sub-Committee may be of interest.

Example I.—Trench Mortar Bombs in Phosphoric Cast Iron

Several methods have been used quite successfully for the production of T.M. bomb body castings in green sand moulds without the use of feeding heads. According to the type of tackle available, these may be cast either vertically with the tail up, vertically with the nose up, or on the flat. In nearly every case, however, this entails the use of cast iron with comparatively low phosphorus content, certainly not over 0.5 per cent.

In order not to exceed this maximum phosphorus content, it is necessary to include a considerable portion of hematite, refined iron, steel scrap or similar low-phosphorus materials in the mixture. Since only very moderate physical properties are required in this type of casting, methods have been successfully devised to make use of phosphoric iron with a final phosphorus content of 0.9 to 1.2 per cent.

In order to achieve complete pressure tightness with this type of high-phosphorus composition, the most reliable method is to cast the bomb bodies vertically, with the tail uppermost and with the addition of a suitably designed feeding head on the top of the casting. This feeding head need not be of large proportions, provided it is so designed that it is the last portion of the casting to solidify and thus provides a suitable reservoir of liquid metal to feed the casting proper. The accompanying sketch (Figs. 1A and 1B) gives details of the design of feeding head most usually adopted.

It is assumed that the moulds will be produced in green sand on moulding machines or by plate moulding. The exact method will depend on the type of tackle available. If it is desired to mould the castings vertically, then the joint will be at the middle of the band in a simple two-part mould. When this method is adopted, it will, of course, be necessary to use loose feeding head patterns in the cope portion of the mould. These will be withdrawn from the top side, leaving open feeding heads. The runner will be located on the joint of the mould, and the actual ingate must be kept as small as possible, in order to prevent any risk of "drawing" from the thicker portion of the gate. This latter tendency can be obviated by the application of jet type runners placed directly over the feeding head, but of course this involves the use of an additional top part to carry the jet runners.

When commencing production for the first time in any foundry it would be much more economical to use half patterns mounted on plates complete with feeding heads and runners. The moulds are then made on moulding machines or by plate moulding on the flat, in simple two-part boxes adapted for vertical casting. In order to avoid the risk of swollen castings or "burst outs," it is a very simple matter to apply loose clamping plates when the boxes are upended for casting. Fig. 2 illustrates this second method.

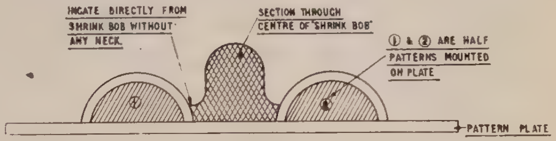
INGATE DIRECTLY FROM SHRINK BOB WITHOUT ANY NECK
SECTION THROUGH CENTRE OF SHRINK BOB
① & ② ARE HALF PATTERNS MOUNTED ON PLATE
PATTERN PLATE

FIG. 3.—SECTION THROUGH TWO HALF PATTERNS SHOWING TYPICAL "SHRINK BOB" OR "BLIND FEEDER." BOMB BODIES CAST ON FLAT AND MAIN GATE INSERTED BETWEEN THE SHRINK BOBS FOR EACH 4 CASTINGS IN 2 PAIRS.

Where it is absolutely impossible to use feeding heads or cast the bomb bodies vertically, it may be just possible to cast them on the flat in phosphoric cast iron, by making use of the well-known practice adopted by malleable iron foundries by the provision of runners combined with "blind risers" or "shrink bobs" (see Fig. 3).

Example II.—Coupling Castings

Certain coupling castings present special difficulty in the foundry and have, therefore, been made in low-phosphorus, low-carbon irons, in the main because this type of casting (Fig. 4) is essentially a compact mass of metal which must not only be machined on all its faces, but which is subject in most cases to operations which will reveal any suggestions of porosity in its interior structure. This example shows how one foundry, by careful attention to method, has been able to raise the phosphorus content of the mixture employed for these castings. The foundry from which this example is taken has a very large proportion of its output in castings of this type, and until comparatively recently the iron used was of the order T.C 3.0 per cent., P 0.25 per cent. max., with silicon variations according to size and section. The castings vary in weight from 14 lbs. to 15 cwts., the majority falling between 100 and 750 lbs.

Experiments were conducted to ascertain the possibility of using a higher phosphoric iron with, incidentally, a higher carbon content. These experiments were successful, the final analysis for one size of casting being T.C 3.28, Si 1.27, Mn 0.58, P 0.63 and S 0.14 per cent., with a tensile strength of 16 tons on the 1.2-in. bar. Equally successful results were obtained on other sizes of castings, modifying the silicon content as necessary.

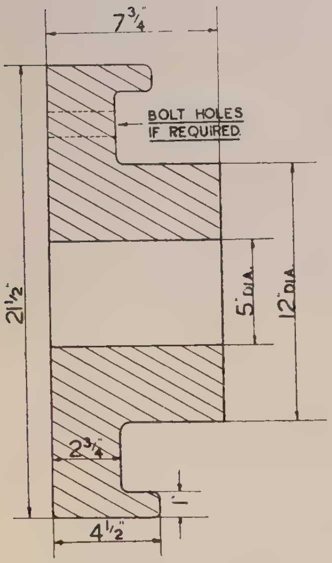

Fig. 4.—Section of Typical Coupling with Dimensions.

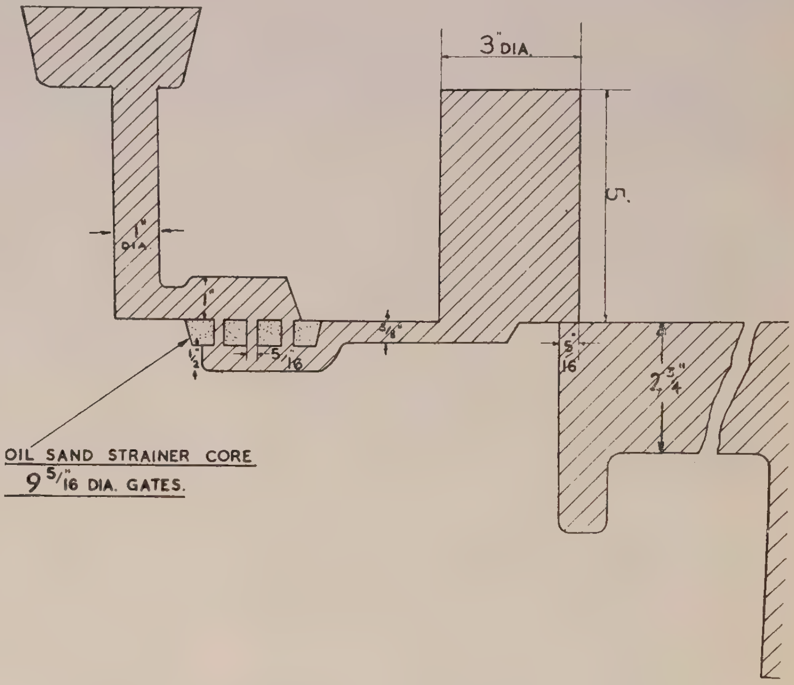

Fig. 5.—Method of Running Coupling showing Cross-Section through Runner/Riser and Part Section of the Coupling Casting.

The successful adoption of the higher phosphorus iron depends on the running technique employed, as illustrated in Figs. 5 and 6. Rod feeding is never used, except with unusually long bosses, and then only in conjunction with the self-feeder on the rim. It is of interest to note that in the majority of cases the bolt holes are bored out of the solid and very rarely do these show any signs of porosity.

The method of production necessitates the use of hot metal and relatively slow pouring, and thus the moulds have to be strongly constructed, particularly the top part. It will be observed that in this case it has been possible to use an iron with 0.3 per cent. P above normal practice, thus reducing the steel consumption without prejudicial effect on the castings produced.

Example III.—Centrifugal Casting

Centrifugal casting, where it can be applied, provides an admirable means of producing sound strong castings from high-phosphorus cast iron. It is, of course, generally applied to simple castings, such as cylinder liners in which P of 0.9 per cent. is regularly used, and it can also be applied in conjunction with composite assemblies where centrifugally cast bushes or liners may be incorporated.

A particularly interesting example is in the centrifugal casting of trench-mortar bombs, though, of course, this practice is limited in its scope, as it calls for special plant. A firm, arising out of their experience in the manufacture of centrifugal cast pipe using Derbyshire iron, conceived the view that the adoption of the centrifugal casting process for the production of bombs would enable such castings to be produced in phosphoric iron to meet the requirements as to freedom from porosity. A centrifugal casting process has been developed specially for the production of these castings.

The mould, incidentally, itself made from 66 per cent. Derbyshire pig and 33 per cent. returned scrap, is arranged to rotate about its vertical axis, and corresponds to the external shape of the bomb casting. It is split along a horizontal plane corresponding to the point of maximum external diameter of the bomb, and so arranged that the bomb is cast with the open end down and the solid end up. An oil-sand core is used. The mixture of iron used for the bombs consists of Derbyshire pig-iron, returned scrap and scrap from the vertical cast-pipe foundry or the spun-pipe foundry on the same plant. The approximate chemical composition of the finished bombs is as follows:

Si, 2 to 2.1 per cent.; P, 1 to 1.3 per cent.; and Mn, 0.4 to 0.45 per cent.

The percentage of rejects due to porosity is negligible, and would not amount to a fraction of 1 per cent. The bombs are tested to 1,000-lb. hydraulic pressure at the works in the "as-cast" state, and to 100-lb. air pressure submerged in water after machining.

Example IV.—Importance of Casting Temperature Control

The importance of casting temperature control is recognised by all foundrymen. The following describes a modern method of determining casting temperature.

The Schofield pyrometer is used in steelworks to measure the temperature of steel in open hearth and other furnaces, and in ladles. It is easily modified for cast-iron foundry use and, for practical purposes, consists of a 4-ft. platinum/platinum-rhodium thermocouple (diameter of wires 0.5 mm.), flex leads and a portable indicator. This gives temperature readings accurate to two or three degrees Centigrade in ten seconds, which is adequate for all normal foundry purposes. The Cambridge Instrument Company, Limited, makes a workshop potentiometer for steel-melting temperatures which can be calibrated over the cast-iron range, and gives an accuracy of 1 deg. C., in two to three seconds.

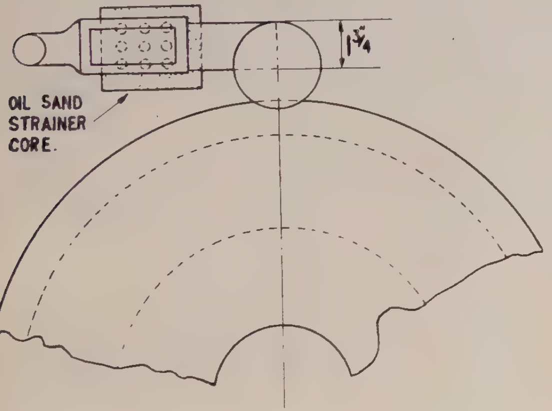

FIG. 6.—PLAN SHOWING RUNNER AS IN FIG. 5.

A sheath lasts up to twenty times with care, but the initial rate of breakage is higher until people get used to handling the pyrometer with reasonable care. In the space of a month this instrument passed through the stages from a new and delicate untried research tool to a normal foundry control instrument used by charge-hands and foremen with confidence. Maintenance may be carried out by a junior laboratory assistant. The feature which appeals strongly is that temperatures can be accurately and quickly determined through blacking or slag. If the couple is broken or damaged by metal, the instrument will either not register or give such impossibly high results that the fact of its having broken is obvious.

The use of the instrument interests moulders, and they vie with each other in the use of the instrument and begin to take an intelligent interest in the casting temperatures. The results of accurate casting temperature control in ensuring soundness are most marked. Troubles due to mis-running, sinking and porosity can be minimised and greater confidence felt in founding higher phosphoric mixtures if the casting temperature is accurately controlled. Wasters, in certain castings which have to stand a porosity test, have been reduced from 20 to 5 per cent. by casting temperature control. Porosity was at the ingates.

Example V.—Machine Tool Castings

In machine tool practice a phosphorus content of about 0.8 per cent. is regarded as satisfactory, although this figure is higher than pre-war practice. Strength to meet B.S.S. 786, Grades 1 and 2, can be obtained with this phosphorus figure. Other makers have found it possible to use considerably higher phosphorus, one successfully working with mixtures of Derbyshire irons and scrap, combined with extensive use of denseners and hot pouring. The use of denseners has had to be greatly extended to compensate for the higher phosphorus now used.

In certain cases, however, phosphorus lower than 0.8 per cent. is necessary, particularly where heavy T-slotting is involved, when figures as low as 0.3 per cent. may be necessary in extreme cases; 0.6 per cent. phosphorus, combined with a fairly low total carbon, is regarded as the high limit for flame hardened lathe beds.

Use of Denseners

During the past twelve years a special densening technique has been developed by one machine tool maker for a wide range of medium and heavy castings, and using a wide range of metal compositions. The technique is, however, extremely involved and caution is advised in the use of denseners by those who may be inexperienced; one does not turn to denseners if reasonable results can be obtained from the metal along with correct foundry technique.

There are many aspects to consider, such as: (1) Quality of metal to be densened; (2) ratio of section of densener to section of casting to be densened; (3) design of densener in respect to design of the particular area to be densened; and (4) composition of the material composing the densener.

Each class of casting can only be dealt with when all conditions are known. Under such restrictions no more than some generalisations can be given:—

(*a*) Denseners may be made of a variety of materials (as well as section and volume) such as steel, cast iron, silicon-carbide, refractory bricks of various conductivities, etc.

(*b*) In light castings, disturbances on the surface of the densener are mostly due to moisture, rust or excessive application of oil coatings applied to the densener.

(*c*) In medium and heavy castings, defects occur from overheating and a sharp rise in the temperature of the densener before the metal of the casting has solidified, rather than from moisture on the surface of the densener.

(*d*) With green-sand light castings, the surface of the densener should be protected by applying a trace of machine oil to the surface exposed to the molten metal and the slightly oil-wetted surface rubbed over with plumbago blacking.

(*e*) Denseners applied to dried sand moulds should be coated with a refractory wash and dried along with the mould.

(*f*) Whether used in green or dry sand moulds the densener, of course, should be free from corrosion. If rust is present on a densener used in a green-sand light casting mould, a blown casting may result, and if a densener has a rusty surface and it is put into a dried sand mould and a refractory applied to the corroded surface, the gas evolution from the rust will blow off the refractory coating and expose the densener to a burning-on action by the molten metal, resulting in blowholes, often very large ones.

From the foregoing, it will be seen that the denseners must be used clean and all effort made to prevent an overheating of the metal of a densener, whenever it is made of metal. It is, therefore, important that metal denseners should be located in as remote a position as is possible in respect to the entry of the metal. The least that one must do is to avoid the direct impingement of the metal entering the mould, on to the metal densener.

Example VI.—Late Silicon Additions—"Inoculation"

Detailed consideration of inoculation technique and the highly satisfactory results obtained by its adoption are outside the scope of the present Report. In view of the urgent necessity for meeting specifications with a lower grade of raw materials than would normally be used, however, the Sub-Committee urge all ironfounders to adopt this technique wherever possible and desirable, in order to obtain the best results from the available materials.

The final silicon content of cast iron poured into moulds must be controlled within reasonable limits to give a suitable relationship between carbon and silicon contents and the rate of cooling which is determined by the sectional thickness of the castings. Late silicon additions made to the metal at the furnace spout must also conform to the above general principle, but the final silicon content can usually be somewhat higher than normal, other things being equal, with beneficial results.

Summarising what has already been published, the Sub-Committee recommend that between 0.5 and 1.0 per cent. silicon should form the late addition, irrespective of the amount of silicon in the metal as charged to the furnace. While early practice favoured the introduction of ferro-silicon in powder form, granular form of pea size or even larger is now preferred. This preference, however, may depend to a certain extent on the silicon content of the ferro-silicon readily available. It is usually considered that the powder form is quite effective when high silicon ferro-silicon is being used, as the bulk to be added is not very great. With ferro-silicons of lower silicon content, however, it is better to use pea size material.

Inoculation should take place as late as possible, since its beneficial effect disappears after an interval of 15 to 20 min. Where fairly large quantities of metal are being treated, silicon treatments should be so arranged that the late addition is made near the end of the last tap, so that not more than, say, 10 minutes' time elapses between the completion of the silicon treatment and the pouring of the last mould from that particular batch of metal.

Generally, the inoculant will mix satisfactorily with the molten metal stream without the introduction of any special device. If, however, there is reason to doubt the effectiveness of the inoculation, "step" bricks or similar baffles can be built into the furnace spout, to provide some degree of turbulence which assists in the absorption of the ferro-silicon. For further particulars reference should be made to the Papers given in the list of references in Appendix 2.

Example VII.—Wartime Mix for High-Strength Cast Iron, containing Chromium

Following the control of nickel and the curtailment of high-grade raw materials, one member has adopted the following wartime mixture of metal for light Diesel cylinder head and general castings down to ¼ in. thick to meet B.S. 786, Grade 2. It will be noted that a late silicon addition is used.

55 per cent. refined pig (T.C 3.1, Si 1.7 per cent.).
15 per cent. steel scrap.
26 per cent. returns from same mix.
4 per cent. ferro-silicon, ferro-chrome and ferro-manganese.

Granulated 45 per cent. ferro-silicon is added at the spout to raise silicon 0.4 per cent. to yield the following average analysis:—T.C, 3.2; Si, 2.1; Mn, 1.2; P, 0.25; and Cr, 0.28 per cent. This metal is regularly giving 20/21 tons per sq. in. on the 0.875-in. dia. bar.

Although this mixture was primarily designed to produce high strength, and raw materials were chosen from available foundry stock, not specially purchased at the time of the first trial casts, it showed that good tensile figures could be obtained with high-carbon cast iron, as carbon percentages up to 3.4, and even as high as 3.5 per cent., have been obtained without any noticeable effect on tensile strength.

Tensile strengths of about 20 tons per sq. in. are obtained with silicon at 2.0 to 2.2 per cent. Although it was found that by increasing the steel in the charge by 10 per cent., and decreasing the silicon to 2.0 per cent., a very slight increase in tensile strength on the 0.875-in. dia. bar resulted, the lower silicon content was not found suitable for the cylinder work for which the metal was designed. These results are largely due to the low phosphorus content of about 0.25 per cent. and to inoculation at the spout.

The Future

It is very difficult to make suggestions as to methods to be adopted if supplies of low-carbon and/or low-phosphorus materials become further restricted, particularly as the extent to which this has been carried to date varies so much in individual foundries. Some of the suggestions offered below may, therefore, have already been widely adopted, and should have been if not. Moreover, some of the possibilities, such as partial Bessemerising, are impracticable, owing to the difficulty in obtaining the necessary plant, while labour supply difficulties may also prevent or limit the adoption of other suggestions.

Special attention should be given to the suggestions listed under the heading "Meeting the Position." Other recommendations are:—

(1) Careful scrutiny of specifications by buyers to ensure that a higher quality of iron is not demanded than is absolutely necessary.

(2) Study of gating and feeding methods, particularly the latter, to ensure adequate supply of liquid metal to prevent porosity in heavy sections, and, combined with this, the use of denseners, and attention to moulding-sand conditions. In short, the establishment of a high standard of foundry technique.

(3) Maximum use of furnaces, such as electric and rotary, and the extended use of these furnaces for duplexing. In these furnaces there is no carbon pick-up and nearly always a reduction in carbon content, and generally much higher test results are obtained.

(4) Manufacture of own refined pig-iron from local steel scrap which is of such a type as to be unsuitable for direct use in mixtures. This should be restricted to extreme cases, owing to fuel consumption involved. Where briquetting plants are available, these should be used to the utmost, and low-phosphorus borings segregated for briquetting.

(5) Close cupola control, including ensuring that cupola is working under "optimum" conditions (incidentally effecting fuel economy thereby).

(6) Segregation of different qualities of foundry scrap for remelting and avoidance of contamination of low-phosphorus mixtures by either high-phosphorus foundry scrap or high-phosphorus cupola charges following closely on low-phosphorus charges in the furnace. In certain foundries it might be possible to run high-phosphorus and low-phosphorus irons on alternate days.

(7) A reversion to the older method of getting good castings by concentration on silicon control, running varied silicons to suit different thicknesses of castings, as distinct from the more modern way of using a low-phosphorus, and possibly low-carbon, iron which will suit a wide variety of sectional thicknesses.

(8) The use of late silicon additions as discussed above.

Meeting B.S.S. 321 and 786 with Native Materials

The chief interest lies in the extent to which higher phosphorus can be used to meet the various specifications, particularly the higher grades of B.S.S. 786. In this connection the following communication to the Sub-Committee is of interest:—

B.S.S. 321, Grades A and C.

Tensile Strengths on 1.2*-in. dia. Test-Bars* 11 *and* 9 *tons per sq. in.*—These specifications do not call for any special remarks. The phosphorus contents can reach even 1.6 per cent., as exemplified by Northamptonshire pig-irons, when melted with a high proportion of mixed low-grade phosphoric scrap iron. It is necessary, of course, even in these low-grade cast irons, to adjust the silicon content to correspond with the sectional thickness of the castings.

B.S.S. 786, Grade 1.

Tensile Strength on 1.2*-in. dia. Test-Bars,* 14 *tons per sq. in.*—It should be possible to meet this specification easily with phosphorus contents up to 1.2 per cent. This means that all types of phosphoric pig-iron, with the possible exception of Northamptonshire grades, can be used, together with engineering quality mixed cast-iron scrap. This allows for the use of all types of Derbyshire iron with a phosphorus content of approximately 1.2 per cent. If any foundry has real difficulty in meeting the mechanical properties required in this specification with high-phosphorus materials, it is usually due to the fact that the silicon content has not been correctly adjusted.

B.S.S. 786, Grade 2.

Tensile Strength on 1.2*-in. dia. Test-Bars,* 17 *tons per sq. in.*—For most castings it should not be difficult to produce this grade of iron with a phosphorus content up to 0.7 per cent. With careful cupola control and the use of high tapping temperatures, together with late silicon additions, it may even be practicable to increase the phosphorus to a maximum of 1.0 per cent. If real difficulty is experienced in obtaining supplies of refined iron, etc., the more extensive use of low-silicon, high-phosphorus pig-iron with ladle additions of ferro-silicon might be considered for meeting B.S.S. 786, Grades 1 and 2. Such pig-irons are usually low in manganese and adjustments would have to be made by the addition of ferro-manganese. Even then, if difficulty is still experienced, it is a very easy matter to use a proportion of low-silicon or white high-phosphorus pig-iron in the mixture to give a metal as tapped from the cupola with approximately 1 to 1.2 per cent. silicon and add at least 0.5 per cent. silicon to the metal at the cupola spout in the form of ferro-silicon. This will undoubtedly give superior mechanical properties.

B.S.S. 786, Grade 3

Tensile strength on 1.2*-in. dia. test bars,* 20 *tons per sq. in.*—It is almost impossible to produce cast iron regularly to meet the requirements of this grade, and have a certain margin of safety, without the use of comparatively low-phosphorus base materials. A figure of 0.4 per cent. max. is probably on the high side, unless alloying elements are to be used. If this specification has to be made from non-alloy containing cast iron, then the physical properties must be achieved by the use of low carbon material, and preferably with very low phosphorus contents. This involves either the use of considerable percentages of steel scrap and/or refined pig-iron. When producing castings of really heavy section in both grades 2 and 3, it may be advantageous to use chromium additions only in order to get closeness of grain and maintain strength therein. This is sometimes preferable to carrying out silicon reduction to the extreme limit.

B.S.S. 786, Grade 4

Tensile strength on 1.2*-in. dia. test bars,* 23 *tons per sq. in.*—It is considered impossible to meet this specification without the use of alloys and comparatively low-phosphorus contents.

Impact Testing

The Sub-Committee feel that one of the greatest handicaps in using high-phosphorus contents is that they reduce the impact strength of the iron. Present knowledge of this property is very limited, and the use of higher phosphorus in high-duty cast iron is discounted accordingly. If a satisfactory single blow impact test can be evolved that could be generally acceptable, it should be somewhat easier to determine the upper limit of phosphorus to meet the various requirements. It is hoped that the investigation into impact tests, sponsored by the Iron and Steel Control of the Ministry of Supply, will reach a rapid and satisfactory conclusion.

Conclusion

In conclusion, the Sub-Committee wish to state that they realise that their earlier Report* was strongly in favour of low-phosphorus cast iron, and, as an easy and reliable way of securing good results, and a consistently high standard of castings, this conclusion is still considered sound. Present supply conditions, however, demand that low phosphorus should be avoided wherever possible, and the Sub-Committee feel that it is desirable under present conditions that the greatest possible use should be made of indigenous raw materials.

APPENDIX 1

SELECTED BIBLIOGRAPHY ON PHOSPHORUS IN CAST IRON

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DISCUSSION

MR. P. A. RUSSELL, introducing the Report, said the Sub-Committee had felt that, inasmuch as the problem of the supply of raw materials had been a difficult one, they might with advantage prepare the Report on the basis of their personal experiences so that individual foundrymen would know what others in the industry were doing. It might be, of course, that on the whole the industry had done better than the Sub-Committee knew.

MR. H. H. SHEPHERD, who opened the discussion, congratulated the Sub-Committee upon its very concise and valuable Report. After asking for information as to the cost of the Schofield pyrometer, he quoted the last sentence of the section of the Report headed "Use of Denseners," that "the least that one must do is to avoid the direct impingement of the metal entering the mould on to the metal densener," and emphasised its particular importance to the grey iron and the malleable-iron founders.

Discussing the modern practice of making late silicon additions and the reference made in the Report to the introduction of ferro-silicon in powdered form, he asked whether the Sub-Committee favoured the use of, say, 75 per cent. ferro-silicon. His final point at this stage was that the Sub-Committee had omitted to mention the improvement effected in the machinability of castings by making late silicon additions. He used late silicon additions very largely with a view to adding machinability, and the benefits derived in that direction were remarkable.

The Phosphorus Bogey

MR. F. J. COOK (Past-President), whilst expressing his appreciation of the Report, said he was surprised that the old bogey of phosphorus content should still arise. Provided the total-carbon/silicon ratio was correct, phosphorus could be used to the extent of at least 1 per cent. in irons for making cylinders of, say, from $\frac{3}{4}$-in. to $1\frac{1}{2}$-in. thickness, and it would not give rise to porosity. The reason that the phosphorus content of cylinder irons had been reduced to a low figure was that otherwise automobile cylinders were so thin that the founder could not achieve the total-carbon/silicon ratio necessary to produce a reasonably soft casting. Hence the necessity for low phosphorus in this class of work.

MR. J. BLAKISTON, referring to late silicon additions, said that the Sub-Committee had specified the addition of ferro-silicon in powdered form, which was the most wasteful form. It should be added either in the pea size or the walnut size. Late silicon additions definitely improved a phosphoric iron casting and reduced the tendency to draw. Complimenting the Sub-Committee on having drawn attention to the use of "shrink bobs" in general casting production, he said they did overcome shrinkage difficulties in many cases, and it was surprising that very many foundrymen never dreamed of resorting to their use in order to overcome their difficulties.

The only method mentioned in the Report to which he took strong exception was the suggested method of manufacture of a cast-iron coupling in phosphoric iron. One of the most important machining surfaces on that coupling was cast "up over," which was all wrong; the result of the proposed method of casting was to form a trap for the gases, so that as they were generated they would have to vent down. It was well known that pre-venting was one of the secrets of obtaining soundness in cast-iron components, particularly in the shoulders. In the Black Country the coupling in question was being cast successfully from a phosphoric iron. It was moulded with the flange "down over," the set-up being very simple; the runner came straight down and entered the side of the coupling tangentially, there being no risers or feeding heads. The whole secret of success was to achieve the right casting temperature.

A pencil-type runner was used, and the metal passed through a small ring core, the holes being of needle size. The casting temperature was controlled at a very high figure, and the size of the holes was such that the time occupied in filling the mould was approximately $1\frac{1}{2}$ min. He believed that 99 per cent. of the castings were produced, without any trace of porosity or draw, in phosphoric iron.

Recalling Mr. Cook's comments on the phosphorus bogey, he said that with the introduction of low-phosphorus iron the general engineering industry had experienced excessive wear in iron castings. High-phosphorus irons, on the other hand, gave exceptionally good wearing properties. Some of the old machine tools, which were still running, after 70 years' service, had practically the same clearances in the bearings as when they were first constructed; invariably the castings were made in high-phosphorus iron. Those castings had a very open appearance, but they displayed the characteristic of good wear resistance, which was peculiar to phosphoric iron.

Finally, he said that the best cast iron which would stand up to the latest developments in tungsten carbide forming and diamond cutting was one containing 1.8 per cent. phosphorus. This mixture was found to be superior to any alloy iron for the cutting and lapping of these extremely hard materials.

MR. W. G. THORNTON, who said that his experience concerning the casting of the coupling referred to in the Report was exactly similar to that of Mr. Blakiston, asked the Sub-Committee for information as to the life of denseners.

Impact on Increased Man-hours

MR. G. W. ROUSHAM drew attention to the reference in the Report to the silicon/carbon balance, and asked if the Sub-Committee could publish it in tabular form. Bearing in mind that, in addition to supply difficulties, there was also the problem of labour shortage, he said it seemed, from a consideration of the Sub-Committee's findings generally, that the use of high-phosphorus iron was a compromise rather than a definite solution of the raw materials problem. For making such things as bombs, and so on, it was obviously useful to experiment with a view to using as far as possible the materials indigenous to this country. But surely labour was just as scarce as materials, and he suggested that it would be advisable to allow jobbing founders to have certain materials other than the compromise materials, to enable them to avoid scrap and thus achieve economy in labour.

Commenting that the Sub-Committee appeared rather to deprecate the manufacture of refined pig-iron by a foundryman for his own use, Mr. Rousham said the manufacturers of cupola-melted refined iron for sale used their hematite presumably with the idea that, say, 50 tons of hematite iron would produce 100 tons of low-phosphorus pig-iron. But the foundryman could produce, with 50 tons of hematite iron, 100 tons or more of castings, and it seemed to him that that might be a more economical use of hematite iron.

Phosphorus in American Irons

MR. SHEPHERD, discussing phosphorus content, suggested that the objections to high-phosphorus cast irons might be conditioned to some extent by the fact that phosphorus, which was present in indigenous irons, was cheap, and because it was cheap we did not want it. It was that sort of mental process which led some men to drink whisky instead of water, because water was cheap! Until a few years ago the Americans had been scared by high-phosphorus iron. There were very few high-phosphorus irons in their country, their highest phosphorus content being in the region of 0.8 per cent., and they had had no experience of any higher phosphorus content. As a result, they had developed their metallurgical technique along the lines of medium- and low-phosphorus irons.

He had taken part in some very heated discussions on the matter when in the United States. Imagine his surprise, therefore, when he saw an article published in one of the American house journals—which he had kept because it constituted documentary evidence! In this McKenzie had assured his readers that he would publish a whole series of further articles to prove that higher phosphorus contents were of value in iron castings and that the opposite school of thought was very often wrong and suffered from "Phosphobia"! McKenzie had stated that high-phosphorus irons gave better properties, and certainly better wearing qualities, than low-phosphorus irons. From those articles, and his own experience, Mr. Shepherd had gathered that, as the result of taking phosphorus out of the iron, it had had in many instances to be replaced by other materials. Metallurgists had started by using nickel, but were told that this resulted in an iron which was rather soft. Then they included chromium to harden it; and later it was suggested that "a pinch or two" of molybdenum would even things up; this was the general picture, as he saw it. It was realised that there were numerous cases where alloy additions were necessary, but it had been overdone. He urged that, if there had been an endeavour to use high-phosphorus irons whenever possible, it would not have been necessary to use alloy irons in such a way that they tended to become common practice rather than for special requirements.

MR. A. E. MCRAE SMITH agreed entirely with the references made to the superior wearing qualities of the high-phosphorus-containing irons. At the same time, there was the problem of their castability. It was well known that the liquid shrinkage characteristics of those higher-phosphorus irons was very poor. An excellent Paper by C. A. Timmins, of Climax Molybdenum, published about 12 months ago, showed that the difference between liquid and solid volume increased very rapidly as the phosphorus content increased. He could not see how some of the very complicated internal combustion engine cylinder block castings could be produced completely free from liquid shrinkage in high-phosphorus iron. He would like to ask Mr. Cook how he made such castings from high-phosphorus cast iron.

Phosphorus in Cylinder Practice

MR. F. J. COOK replied that he had made thousands of complex cylinder castings, about as complicated as they possibly could be, in irons containing 1 per cent. phosphorus; bearing in mind particularly the maintenance of the proper carbon/silicon ratio, he had never experienced any porosity trouble whatever in those cylinders, which had to withstand steam pressure up to 300 lbs. per sq. in., at a temperature of more than 400 deg. F.

MR. MCRAE SMITH said that he was speaking of automobile cylinders, not steam engine cylinders.

MR. COOK commented that one could not produce satisfactory automobile cylinders in high-phosphorus irons with the carbon/silicon ratio specified in the formula. But he emphasised his earlier remark that, in cylinders of from ¾-in. to 1½-in. thickness, there was no difficulty whatever in achieving high strength in high-phosphorus irons. Many years ago he had carried out more than 200 consecutive tests, covering two years' working, using a straight iron with no steel additions. The test figures for those castings were never as low as 14 tons per sq. in., the highest was 19.2 tons per sq. in., and the average for the 200 tests was 16.4 tons per sq. in. The wearing properties in all cases were very much better than in lower-phosphorus irons.

MR. SHEPHERD agreed that there were certain castings which must be made with somewhat lower phosphorus content than was referred to by Mr. Cook. Before the war the industry had become so scared about the use of phosphorus that every so-called modern metallurgist had tried to drive the phosphorus content to the lowest limit. His own view was that one should use as much phosphorus as possible, within reasonable limits, for it was in the national interest to do so, not only in wartime, but also in peacetime. The higher-phosphorus irons formed the basis of the old school of foundry technique, which did produce thousands of tons of really good castings; if these materials were used with intelligence and judgment it should be possible to reduce very largely the cost of mixtures by reducing or in many cases eliminating alloys.

Shock-Resisting Properties

DR. A. B. EVEREST pointed out that, in addition to the influence of phosphorus on soundness, there was another factor which assumed great importance during wartime, *i.e.*, the mechanical or shock-resistance property. Phosphorus had a very deleterious effect on the properties of castings which were required to meet conditions such as those of under-water shock, and there was a tendency for the Services to step up their specifications; that was certainly not compatible with the use of the higher-phosphorus irons.

MR. COOK challenged the statement that high phosphorus content had a deleterious effect on shock resistance. Many years ago, he said, he had published figures relating to irons containing as much as 1 per cent. of phosphorus, which figures showed that, where the carbon/silicon ratio was right, those irons exhibited very much greater shock resistance under the drop load test than did the lower-phosphorus irons.

DR. EVEREST said that for the past two years he had been working on a Committee which was trying to develop a satisfactory impact test for cast iron, in order to satisfy the Service Departments. Much work had been done by that Committee on the influence of phosphorus on impact strength, and there was no doubt that, as shown by tests of the Izod type, as the phosphorus content increased the shock-resisting properties of the iron decreased very rapidly. As an example of the importance of shock resistance, he pointed out that motors were carried on brackets on board ship, and the brackets must have the ability to withstand the effects of shock such as might be caused by a depth charge or something of that sort.

Replying to a request that he should define "high phosphorus content," he said the Sub-Committee had set out in the Report the phosphorus limits which, in the view of the members, should not be exceeded if the various specifications were to be met. In his view it was necessary to limit the phosphorus content to less than 0.25 per cent. in order to meet the highest mechanical or shock-resisting properties specified. Medium shock resistance would be attained with a phosphorus content in the range of from 0.5 to 0.7 per cent. In the native irons, with a phosphorus content of about 1.2 per cent., the shock resistance was generally relatively poor.

MR. J. L. FRANCIS agreed largely with Dr. Everest that the higher-phosphorus irons were less resistant to shock than those containing lower phosphorus contents, but he added that the successful use of irons having the higher phosphorus contents was to some extent, and a not unimportant extent, bound up with the design of the castings to be made. In the case of sand castings having considerable sectional changes, ribs, brackets, water jackets and internal bosses, for example, it was very much more difficult to secure soundness and resistance to hydraulic pressure when the phosphorus content was much over 0.5 per cent. than when it was lower.

There was no doubt that the wear-resistance of castings was increased by the use of phosphorus. But, whilst it might be desirable under wartime conditions to use as much phosphorus as possible in the mixtures, foundrymen must ensure that that did not result in the production of wasters, which would entail extra work (at a time when labour was not easily available) and the use of extra fuel.

Cast-Iron Guns

MR. BLAKISTON recalled that at a foundry he had visited recently there was included amongst the scrap a consignment of cast-iron guns which were about 120 years old. The iron of which they were made contained about 1 per cent. phosphorus. No matter how great the shocks to which the castings were subjected, which included a 1-ton drop from a height of 30 ft., it was found impossible to break them; eventually the gun barrels had had to be drilled all the way round before they could be broken down. Perhaps the Sub-Committee would be interested to find out why that iron possessed the superior characteristics which everyone tried to develop. In reply to a question, Mr. Blakiston said the carbon content was about 3.3 per cent., which was not abnormally low, and the silicon content was about 1.3 per cent.

DR. EVEREST commented that surely the important factor in the case referred to was that of the section. He added that the reference to the particular guns mentioned was perhaps a red herring, because, after all, the foundry concerned had not tried to break down guns made with other grades of iron.

MR. R. C. TUCKER was of the opinion that the guns referred to were made of cold-blast cast iron, so that they possessed superior toughness; and he suggested that if one tried to cast a gun-barrel with a high blast temperature modern pig-iron, one would not achieve the same results. With 1.3 per cent. silicon one obtained a very nice grey-iron structure in the old cold-blast cast iron. The good results obtained were the result of the blast-furnace conditions under which the irons were made, and he urged that not sufficient fundamental research had been directed to that matter.

As the result of a pre-view of the Sub-Committee's Report, he had been able to overcome a foundry difficulty. In casting trench-mortar bombs by the method shown in Fig. 1 (a) of the Report, with the runner on the band, a certain number of scrappers (not "wasters") resulted through porosity on the band, as shown by air test. By adopting the method of manufacture shown in Fig. 1 (b), using top pouring, the troubles were overcome, even when using iron containing 1.2 per cent. phosphorus. Thus, a defect involving porosity at the ingate was overcome by a change of foundry practice. Whereas the low-phosphorus cast irons were comparatively foolproof in a jobbing foundry, the founding of the higher-phosphorus irons needed great care.

Schofield Pyrometer

Dealing with Mr. Shepherd's question concerning the cost of the Schofield pyrometer, he said it was quite cheap, though he could not give specific figures; and its reliability had been proved in use, after the initial teething troubles had been overcome. The only maintenance item was the replacement of the sheaths, which cost about threepence each and lasted for about 20 determinations; the time occupied in replacing a sheath was about 3 min. One could buy a workshop potentiometer for about £18, or an indicating instrument. The platinum and platinum-rhodium thermocouple represented a first cost of not more than £4 or £5, which was not outrageous. It was difficult ordinarily to get a look at the iron before it was actually poured into the mould, because of the dirt, etc., on the top. The Schofield pyrometer, however, could be inserted straight through the slag. If the iron were reasonably hot, there was no difficulty in making an accurate estimate of the temperature. Again, if the iron were hot, the sheath was not damaged, but sometimes, when the iron was of the sticky type, it was necessary to replace the sheath after each determination.

Finally, Mr. Tucker recalled an instance in which, in the making of certain castings which had to be subjected to porosity tests, the percentage of wasters had been reduced from the former level of anything from 20 to 50 down to a regular 10 or 15 per cent. as the result of proper temperature control. The economy effected in that direction had covered the cost of the instrument hundreds of times.

The PRESIDENT (Mr. D. Sharpe) agreed that, in the case of irons having a really high phosphorus content, beyond that mentioned so far in the discussion, the pouring temperature and the condition of the mould had a great deal to do with the porosity or the soundness, apart altogether from the chemical composition.

Life of Denseners

MR. E. LONGDEN, who was invited to reply to Mr. Thornton's question concerning the life of denseners, said it depended on the type of casting, the temperature to which the denseners was subjected, and its location in relation to the runners, gates, and so on. The growth was not necessarily a hindrance to its repeated use; rather was its life conditioned by the maintenance or otherwise of its shape which would allow it to fit correctly on the location to be densened.

In heavy castings, where there was overheating of the metal of the densener, the aim was to gate the castings at points where there would be no direct impingement of the metal on to the densener, so that it would remain as cool as possible. The desirable section of densener to use again depended on the amount of metal which might be poured past the place at which the densener was situated. Any material which effectively protected the densener would help to minimise its growth. A refractory which would maintain its condition on the face of the densener was to be recommended. Denseners were not necessarily made of metal; various refractories, with an appropriate heat conductivity, could be used.

Incidentally, Mr. Longden said that the phosphorus content of the metal did not trouble him a great deal if below 1 per cent., for he was concerned with medium and heavy castings. A silicon content of from 1.0 to 1.2 per cent. and carbon content of about 3.1 per cent. would give sound metal. In certain classes of massive castings a manganese content of below 0.5 per cent. had given an excellent structure when combined with low silicon and moderate carbon content.

CONVENER'S REPLY

MR. P. A. RUSSELL, replying to the discussion, dealt first with Mr. Shepherd's question concerning the addition of ferro-silicon. It was stated in the Report, he said, that "while early practice favoured the introduction of ferro-silicon in powdered form, granular form of pea size or even larger is now preferred." The Sub-Committee endorsed that, and might have stated even more strongly that the powdered form should be avoided. Whilst no mention was made in the Report of the improved machinability resulting from late silicon additions, he agreed with Mr. Shepherd that that was a very important factor.

Commenting on Mr. Cook's remarks concerning the maintenance of the proper carbon/silicon ratio, he drew attention to paragraph (7) in the section of the Report headed "The Future," in which the Sub-Committee advocated a reversion to the older method of getting good castings by concentration on silicon control, by running varied silicons to suit different thicknesses of castings, as distinct from using a low-phosphorus, and possibly low-carbon, iron which would suit a wide variety of sectional thicknesses. That, he agreed, did not meet Mr. Cook's point entirely; it might have done had the reference been to silicon *and carbon* control.

In reply to the requests for further information on the carbon-silicon balance in relation to phosphorus content, the Sub-Committee felt that the best thing would be to refer those interested to the published work on this subject. Attention is, therefore, drawn to the following Papers:—

(1) F. J. Cook, "American versus British Grey Cast Iron." Proc. Inst. British Foundrymen, 1921-22, Vol. 15, pp. 287-304.

(2) R. Ruer and F. Goerens, "On the Mechanism of Melting and Solidification of Iron Carbon Alloy." Ferrum, 1916-17, Vol. 14, p. 161.

(3) G. Brinkmann and P. Tobias, "On the Relationship between Chemical Composition and the Mechanical Properties of Cast Iron." Die Giesserei, 1941 Vol. 29, September 18, pp. 317-320.

(4) Research Committee on High-Duty Cast Irons for General Engineering Purposes. Second Report—Phosphoric High-Duty Irons. Institution Mechanical Engineers, 1941.

As to Mr. Blakiston's objection to the method of manufacture of a cast-iron coupling in highly phosphoric iron, he said that, whilst it was appreciated that a great many castings were made in high-phosphorus iron, it was known also that certain people always made couplings in low-phosphorus iron. The case referred to in the Report provided such a startling example of how hematite and steel had been saved that it was considered to be well worth bringing forward. He believed the particular couplings under discussion were rather heavier than the average, and perhaps that explained why low-phosphorus irons had been used previously.

It was true that the Report did not emphasise the influence of phosphorus on the wearing qualities of cast iron. But the Sub-Committee did not attempt to write a general treatise on phosphorus; it was trying to help foundrymen who had to use irons of higher phosphorus content than were used formerly.

In reply to Mr. Rousham, he said the problem of labour shortage was somewhat outside the scope of the Sub-Committee; but he sympathised with the idea that if founders could obtain the raw materials they wanted they could ease their labour problem. However, it was not a question of balancing one factor against another, but rather a question of making the best of supplies, of which there was an absolute shortage or limitation; the hematite iron was just not there. Problems of shipping space, and so on, all entered into the general considerations.

All he would say on the discussion concerning high-phosphorus *versus* low-phosphorus irons, was that the use by the Americans of low-phosphorus irons had had possibly an adverse effect upon British practice. But wartime experiences were proving valuable, in that they were enabling us to get away from the low-phosphorus specification where it was unnecessary.

Great care must be exercised in considering American statements on high and low phosphorus since the phosphorus range of American irons is of a totally different order from those in this country. Thus, when an American foundryman spoke of high phosphorus he more often than not meant something less than 0.8 per cent. This point should not be overlooked, as it tends to lead to some confusion in considering American reports on this subject.

With further reference to the information already given by Mr. Tucker on the Schofield pyrometer, it is thought that those interested in this equipment and requiring further information might care to look up the Paper by F. H. Schofield and A. Grace entitled "A Quick Immersion Thermo-Couple for Measuring the Temperature of Liquid Steel both before and after being Tapped from the Furnace," and which is published on page 239 of the Iron and Steel Institute Special Report No. 5, this being the 8th report on the heterogeneity of steel ingots. The pyrometer as adopted for cast iron is substantially the same as that described in the Paper, but with less elaborate equipment required for manipulating the thermo-couple in the iron foundry.

WRITTEN DISCUSSION

Mr. J. L. Francis wrote that in the course of the discussion it was suggested that a table giving the correct relationships between carbon and silicon for different percentages of phosphorus, so that casting trouble from the use of the latter could be avoided, would be valuable. Such information had already been drawn up in the work done on the effect of phosphorus on the shrinkage of cast iron, by the B.C.I.R.A. Since phosphorus increases the fluidity of cast iron and formed a low melting point constituent, it seems obvious that greater skill and precautions would be needed to produce sound castings as its ratio becomes larger, and the tendency for shrinkage trouble and porosity to occur would likewise keep in step with the increase in phosphorus content.

Mr. W. T. Bruce wrote, in reference to coupling castings, that he was extremely interested in the method of making these in 0.63 P iron. The extremely small gate used, and the fact that the liquid pressure from the height of the riser and runner shown will be negligible, calls for particular comment. Further, the fact that an oil-sand strainer core is used for this particular purpose for these castings up to 15 cwts. excited his curiosity. It was a new factor personally with about 13 years' experience on high phosphoric irons alone, to know that castings of so heavy a section and proportionately greater area could be cast successfully with these tiny gates. For the small pulleys, he felt certain that ingates round about the dimensions given would more or less be successful in producing a good casting of this type, provided more liquid pressure was given by the use of more height on the runner and riser. Presumably, of course, the size of the gate and the height of the runners and risers are increased as the dimensions of the pulleys increase.

For his own part, if he were making these castings, he would have the ingate at least three times the dimensions of the gate shown at Fig. 5 for the casting of a coupling of 3 cwts., at the same time increasing the height of the riser and the head twice as much as that shown in Fig. 5, to give increased liquid pressure. The size of the ingates and the heights of runners and risers to be proportionately increased for every 1 cwt. increase in weight on the couplings made. The reasons given for these precautions being to counteract cold lap, cold shut, and the possibility of shrinkage due to the segregation of phosphorus at the point (see Fig. 4) in the metal of the section of the casting all round and above the inner fillet on the 12-in. dia. bush. The metal from the 2¾-in. section on the 21½-in. dimension would have to feed that lowest part, and liquid pressure is important in this extent.

Was it possible that more detailed information could be given in the near future on the casting of these couplings, in weights up to 15 cwts. each, particularly in regard to these matters referred to? It was almost incredible to learn that an oil-sand strainer core either made from sea sand or Leighton Buzzard fine, and bonded with a semi-solid, or one of the proprietary liquid core binders made from linseed oil, sulphate of lye, dextrine, and molasses, could stand up to 15 cwts. of hot metal being poured through it at slow speed. Personal experience of oil-sand cores made only with sea sand or Leighton Buzzard sand with no clay bond or moisture in them was, that in jobs where they were used, the quicker the job was poured the better, because of the danger of the core incinerating in casting.

An oil-sand core with, say, a good proportion of Dullatur sand in the mix with sea sand or Leighton Buzzard sand, plus an added percentage of moisture, would of course stand up to the duty required. Firms had used this mixture many years now in making high-pressure castings of semi-steel.

Mr. E. J. L. Howard wrote that no doubt many methods had been used for the production of trench mortar bombs, all of which have met with some degree of success. He would like to describe briefly the method he had used which resulted in very few rejects due to porosity. The moulds were produced in green sand by plate moulding. Three castings were made per box and cast on the flat. The castings were run about 1 in. below the tip of the nose: a riser was not used, but a good head of metal was obtained by building up the runner box above the moulding box to the extent of 6 in. All moulds were made on machines and then placed on a conveyor. The composition of the iron was between the following limits:—T.C, 3.2 to 3.4; Si, 1.8 to 2.0; Mn, 0.6 to 0.7; S, 0.08; and P, 0.9 to 1.0 per cent.

There seemed to be little doubt that for some considerable time the supply of low-phosphorus iron would be limited and expensive, and many cases where it was deemed necessary to use these irons, equally good results can be obtained by proper attention to what was aptly termed foundry technique.

Sub-Committee's Reply to Written Contributions

The Sub-Committee wish to thank Mr. Francis, Mr. Bruce and Mr. Howard for their further contributions to the discussion of the report. The point raised by Mr. Francis concerning silicon-carbon balance had now been dealt with in the verbal reply to the discussion at the Annual General Meeting.

With reference to comments by Mr. Bruce on the casting of couplings, the Sub-Committee were interested in the experience set out, but in view of the fact that there were clearly a large number of methods which could be successfully applied to the production of a casting of this type, they felt that there was nothing further they could add. The Sub-Committee were in full agreement with Mr. Bruce concerning the necessity for having a correct composition for the oil-sand strainer cores if they were to stand up to the passage of a considerable quantity of hot metal. The use of a core made from sea sand with core oil was clearly not to be recommended, and the type of mixture which the Sub-Committee would put forward as successful in practice was sea sand or equivalent silica sand plus 5 to 10 per cent. of silica flour mixed with any core sand binder and baked at 230 deg. C. The Sub-Committee wished to thank Mr. Howard for the details he gave of his method of producing trench mortar bombs.

Paper No. 773

Industry and Education

By G. L. HARBACH* (Member) and J. R. HORTON* (Associate Member)

PART I.—PREPARATORY EDUCATION

Children leaving school are no longer satisfying the needs of industry and, for two main reasons, the latter has had increasing cause for complaint. First, there is a definite numerical shortage of recruits, as in the textile and foundry trades; secondly, industry as a whole is critical of the standard of education, to be found amongst both elementary and secondary school apprentices and beginners. The present war and the decline in the birth rate have both intensified the causes for complaint, but cannot be held as the initial reason for such a state of affairs. The fact that boys do avoid certain trades, causing a dearth of apprentices therein, means that their outlook has been so formed that they prefer some other occupation; either because it is more agreeable to them, or because they have been led to believe it will be so. The dissatisfaction of industry in general with the ability of the boys expresses some lack in their training prior to entering industry.

Now, the Board of Education contemplates drastic reform of the educational system, the main points of which are stressed as equality of opportunity for higher education, including financial compensation where necessary; raising the school-leaving age to fifteen or sixteen years, and compulsory part-time education up to eighteen years of age. If this means merely an extension and widening of the present manner of education, then industry will receive no benefit from the reforms, and may experience a worsening of the situation now confronting it. To prevent such a happening there must be an alteration in the *kind*, as well as the extent, of the education to be received by the future worker; it is proposed to outline in this Paper a criticism and revision of the present systems, define their relation to industrial needs, and thereby stimulate a discussion to precede the action industry must take to safeguard its future well-being. Education has been so frequently discussed during the last twenty-five years that the authors cannot claim originality or a new conception of the subject; but it is hoped that a review of the salient features will remind members of the urgency of the situation and provide them with sufficient material for the above very necessary discussion.

Past Aspects on Education

Education prior to 1750 was purely academic, and only modified during the next fifty years by the founding of private schools by the manufacturers, who desired a more practical education for their sons. This represents a striking parallel to the situation to-day. Technical education commenced about 1830 with the formation of the Mechanics' Institutes, but was neglected thereafter, in comparison with European countries, by reason of Britain's commercial and industrial pre-eminence during the nineteenth century. It will be realised that this superiority no longer exists to the same extent, and, after this war, will have dwindled still further. The early years of the twentieth century saw far-reaching reforms in elementary and secondary education, using as a basis the traditional, academic standards, with scholarship as the final aim and written examination to provide the test of quality.

Education has been regarded as an end in itself; the ability to earn a living, the qualities of citizenship and knowledge of commercial and industrial conditions, have been shelved as secondary to this end. However, some 550,000 elementary school children leave school each year; 10 per cent. of this number continue with secondary education, and the remainder find work. These last have received an education whose goal has been the passing of the secondary school scholarship examination—78 per cent. of secondary school children are ex-elementary products. The goal of the secondary education is the passing of the Higher Leaving Certificate, Matriculation or Bursary Competition Examinations for University—which in turn is the gateway to the professions, absorbing less than 2 per cent. of the working population. Therefore, broadly speaking, the education of 98 per cent. is subordinated to the ambitions and requirements of 2 per cent.

Distribution of Entrants

Before analysing the changes that will rectify this unsatisfactory state of affairs, it would be as well to consider the proportions of children who will enter industry. Of approximately 20,000,000 workers, about 7,000,000 are employed in registered industrial occupations, including mining and quarrying. Of these, not more than 2,500,000 are in the types of industry which can be allied with founding and engineering—the foundry trade itself absorbs not more than 250,000. Therefore, we must not lose sight of the fact that our types of industry only claim some 13 per cent., and the foundry itself a mere 1.3 per cent. of the total working population. Thus, radically to alter the educational system for all, with an eye to the needs of industry alone, would once again be a short-sighted policy.

The present Minister of Education has proposed a segregation of children, at eleven years of age, into three groups, according to their future vocation, to wit:—(1) Academic and artistic; (2) black-coated workers; and (3) artisans. All education after this division to be classed as secondary. The authors consider eleven years of age is too early to make such a definite decision and, if it should become law, then some provision must be made for easy transfer later from one group to another. Throughout this Paper it has been assumed, with reasons, that children up to eleven years will receive the same education; at eleven they will qualify for an education, for a minority, to be called secondary education, the remainder to receive what the authors will continue to call elementary education until they become of school-leaving age, and take a job.

Early Education

The education of children up to eleven years of age is a problem in which industrial needs must be faded into a pattern, which will give the children a training for future life in general—a design for living. The narrower views of academic scholarship or vocational training for industry and commerce must not occupy a large portion of the curricula, except in so far as either help to further the broader aim of preparing the child for a useful existence. The substance of this instruction is outside the scope of this Paper, but the following points give the framework on which such a course could be built. As at present the brain must be encouraged to think, develop initiative, flexibility and adaptability. Explain that service of some kind or another will be the lot of 90 per cent. of people and that payment in money is not the whole value of service rendered. Abstract subjects can be made more real and understandable by clothing them in forms related to the things seen in actual life. Bring the classics into their proper perspective and concentrate on the correct spelling and writing of English, before instilling appreciation of classic authors. The reason for the different lessons should be explained—whys and wherefors—because the reason for a lesson may be more important than the actual subject matter. Emphasise that clean or dirty hands and clothes are not necessarily indicative of social position. In short, make the world about the child really live instead of leaving him to regard it as something that goes on outside the school walls.

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* The authors are respectively Metallurgist and Assistant Metallurgist, Worthington-Simpson & Company, Limited. Mr. Horton was awarded a Diploma for this Paper.

At the age of eleven a competitive examination for secondary scholarship can be set as now, but based on the revised elementary course. It should not represent a criterion of the factual knowledge contained in eleven-year-old brains, but rather of general ability, designed to test the quickness and initiative of the brain with a view to absorbing further knowledge. Those who continue at elementary schools (unless at, say, thirteen years of age marked ability merits transfer to the secondary course) will be taking a job in four years' time and their studies should now lead towards that goal:—Practical mathematics, competence in handling figures and a knowledge of accounts, the mechanism of Government and social services, with discussion of the types of job the child may take, with particular reference to local trades and what they entail. Emphasis should be laid on practical subjects: wood and metal working, bricklaying, painting, decorating and plastering, gardening, general repair and maintenance, etc. Include such theoretical knowledge as will be useful to the child and make of him a budding handyman, so that, whether he becomes a clerk, 'bus-driver or foundry apprentice, his hands will have learned to co-ordinate with his brain, and he can apply some of his schooling in his new job. Also, he will have gained the basis for some hobby or spare-time occupation that will increase his value to himself, his home and the community at large, *i.e.*, he will have received some training for leisure.

During this time information should be afforded the school authorities of new trends in industry, the state of the labour market and of the advantages and amenities pertaining to any particular trade. An industrial career should be popularised and made attractive in the boys' eyes, just as are the Civil Service, banking, accountancy and architectural careers; many a boy enters these latter careers lured by descriptions of clean hands, short hours and good money, only to find he is unsuited in temperament, and the substance is changed into shadow.

To accomplish this aspect of education each industry, through its technical societies and associations, should form national committees to provide advice and recommendations to the Board of Education; regional committees should be formed from local societies to act in the same capacity with local education authorities. In peacetime the Ministry of Labour in each town has already sponsored a committee composed of representatives of the Chamber of Commerce, executive and operative branches of local industries and the local education authorities, to advise on the employment of youth. It cannot be too strongly stressed that parents, children and school authorities should possess knowledge of the conditions, prospects and vacancies in industry. Also, as one is chiefly interested in what confronts one most, encourage recruits by arranging for publicity and advertisement of industry in a non-technical manner—through the Press, films, lectures and wireless—to attract the attention of parents and children in the desired direction.

Secondary Education

Secondary education should also follow the above lines, with the main difference that the final product must be able to enter a more varied field of occupation, in accordance with the extent and contrasts in the types of knowledge required. The academician, artist, professional, technical and administrative classes all lead from secondary education. None of these must lose touch with the realities of a competitive existence, but the degree of specialisation must be intensified and must involve a segregation of the boys according to the career they intend to follow. The choice of this career cannot be made without a conference between parents, teachers and children, bearing in mind evidence of the boy's particular bent and progress throughout elementary and secondary school.

For the first three years of secondary education all can follow a general course until this conference takes place. Then, at the age of fourteen, sufficient knowledge of the child's ability and tendencies should be available to allow him to commence the vocational stage of his training. It is not the object to turn out a finished article at seventeen years of age, capable of entering fully qualified into an industrial position, but it is desirable to produce a recruit who has absorbed the fundamentals underlying his position, and who will be able to continue his part-time and evening studies while keeping pace with his works' practice. This in contrast to the present-day student needing to concentrate unduly on the technique of a new job and often overloading the brain with studies at night-school.

The Problem of Teachers

The teachers of the new system present a difficulty. At present they are of the "teacher" type—superannuated, socially secure, remote from industrial conditions or discipline—and teach with this outlook. As models for the academic or professional student they are ideal and produce excellent results from these types of student. By the same reasoning, other employments must be represented on teaching staffs by their particular experts. The future of this aspect will solve itself, because the students under the new system will furnish the types of teacher needed. In the meantime look to the ranks of industry and commerce to provide instructors during the transition period.

The technical schools have proved the standby in remedying the defects in industrial recruits. Their system needs little alteration beyond a revision of present curricula to match up with the elementary and secondary school products who will attend them. Overlapping nowadays is unavoidable because the two types of education have different aims. The new scheme endeavours to make these aims the same, and the overlap should disappear.

The educational purist strongly denounces vocational training as being utilitarian and divorced from true education. He fears an ultimate race of robots, bred and trained for the industrial machine. The materialistic industrialist pooh-poohs general education as unnecessary—teach the boy a trade, children will have to earn a living and their education should be subordinated to that end, if robots are the result, they will at least be efficient operatives. The proposed scheme steers a middle course between these two extremities and hopes to appease both.

Example of H.M. Dockyard Schools

As a particular example of such training as has been envisaged, consider H.M. Dockyard Schools; founded 100 years ago and furnishing the craftsmen, designers, technicians and administratives for all variety of trades in the dockyards. An entrance examination not beyond the capacity of present elementary standards admits the boys at 15 to 17 years of age. Over a four-year course they attend lectures, given by professional teachers and qualified dockyard employees, for 12 hours per week, and cover a full-time engineering course. The rest of their time is devoted to practical training in the shops, giving close co-operation between theory and practice. There are upper and lower divisions in the schools, the students being sifted by annual examination and graded accordingly, with the result that fourth-year upper school students are of first-rate practical and theoretical ability and may continue with a university course. Thus the majority of entrants become craftsmen with a sound educational background and the remainder provides men of the highest technical and administrative qualifications. These schools are, of course, Admiralty institutions, but similar schools are working with equal success in other branches of industry.

A frequent slogan to-day is, "Secondary Education for All," but this Paper has delineated elementary and secondary types and expressed the probability that it will still be but a small percentage of the whole that will attain secondary standard. This does not mean that financial considerations will decide the issue, as is largely the case at present, for the authors have stressed equality of opportunity. It does mean that they believe that secondary education for all—for some time to come at least—is unnecessary and would lead to dissatisfaction and discontent. They do not believe in the imminent possibility of a millenium, and therefore most men will still have to do manual and monotonous jobs, whilst others, by virtue of superior ability (not opportunity) will reach higher and more congenial standards of labour. It is therefore contended that sound elementary training for the majority is better than an excellent but unsuitable education for all. Given true equality of opportunity the competitive system of elimination for those who merit secondary training will be fair and impartial, and the unskilled labourer of the future will be unable to say, "I didn't have a chance."

PART II.—INDUSTRIAL EDUCATION

Elementary-school leavers enter industry with unformed minds, with little power of discrimination or choice; they have not taken any real stock of their future, and, being ignorant of their possibilities in life, are often content to fill any post that is vacant when the time comes for them to find a job. The much smaller proportion of secondary and technical school products have gained a sense of discrimination, and are more aware of their capabilities and the uses to which they can be put. Therefore it is found that industries with a large proportion of manual or unpleasant types of labour, under unhealthy or otherwise irksome conditions, are the outstanding sufferers from the present dearth of good apprentices. Such trades can obtain sufficient unskilled or semi-skilled labour, but the more highly educated children will endeavour to avoid entering such industries as long as their ability will find them a job elsewhere.

In support of this contention it is noted that in the textile industry, with its necessarily uncongenial working conditions, those firms which have paid greater attention to the health and general well-being of their workers, suffer least in respect of suitable recruits. If education for all is to be raised to the higher standard contemplated, then the position outlined above will be worsened unless industry as a whole will be able to stand the criticism of the discriminating youth of, say, ten years hence.

Now foundries, textile mills, steelworks, etc., can never become a collar-and-tie job during working hours, but the boy's biggest complaint is not that he is amongst grease and dirt at work, but that he leaves work with evidence of his job still upon his person. That this is not inevitable in the above trades is proved by some of the modern foundries, where workers and staff leave at the same time and are, from personal appearance, indistinguishable. Great stress is laid upon the money incentive, but this is overrated—a boy in the shops frequently gets more money and has better prospects of getting more than his black-coated fellow, but the inferiority attached to manual or dirty work outweighs the advantage of more money. There are at least three points here:—(1) Provide cleaning and bathing facilities; give the operatives accommodation for a suit of working clothes and a place to change at the start and finish of a day's work. (2) Do not make the mistake of thinking that financial betterment will completely overcome the apprentice's aversion to personal discomfort. (3) Discourage the marked segregation between staff and operatives.

Foundry Apprentices

At the moment boys entering the foundry trade have the advantage that workers with technical training are comparatively scarce and are free from fierce competition for executive positions. The above disadvantages largely account for this state of affairs, but the frequently haphazard training undergone by foundry apprentices still further thins out the numbers who may qualify for worthwhile jobs, thus aggravating the present position which so often places non-foundry trained people in charge of foundries—a state of affairs tending to perpetuate the uncongenial conditions.

Foundry work is by nature less subject to rules and standard methods of procedure than other engineering crafts, and it seems that this is reflected in the treatment of the apprentice. He must not be left to "pick up" his trade, subject to the limitations in experience and ability of the moulder to whom he may be attached. If he is to become a craftsman, then ensure that he is given instruction in every class of work he may have to do. All types of moulds, moulding machinery, foundry routine, etc., are to some extent interchangeable. Hints and tips, the best methods of manufacture, necessary precautions and technique for one job, are useful knowledge for others and discourage the watertight compartments common to industrial routine.

The transition from light repetition work to heavy castings shows a series of overlaps, and he who can call on a knowledge of all classes of work will be able to make a better job of any one section of founding. A boy at school, technical college or university follows a set curriculum, designed to attain a specified goal, such as a qualification, degree, or some other evidence of his efficiency in his subject. No one would consider leaving such a student to casual or haphazard methods of instruction. A foundry apprentice in similar fashion is aspiring to the goal of craftsmanship and should follow a definite course, suitably correlated to the type of foundry and the theory underlying the practice of his craft.

Scheme of Foundry Training

With the raising of the school age to 15 years and compulsory part-time education to 18 years of age, it is expected that the latter stage will entail instruction pertaining to the boy's trade as the main factor. By dove-tailing his external education to match his working education, a scheme can be applied which will complete the blend of theoretical and practical training and also shorten the period of non-production, inevitable during the training period. The course for the boy entering the industry at 15 years of age would be on the following lines:—Assuming he aims to be a moulder, commence with general application of the different classes of moulding. The boy should be assigned to a competent moulder in each case and his progress noted periodically by allowing him to make on his own a run of castings representative of the particular section he is in, thus developing at the same time his sense of responsibility and giving him the opportunity to learn from his failures.

From the moulding shops he should spend a period in core, fettling and pattern shops to supplement his knowledge of the materials with which he has been working. Coincident with his shop experience, his part-time and evening schooling should cover the properties and characteristics of sands, fluids and metals, as well as practical mathematics and machine drawing; in short, should explain to him the reasons underlying the practices he will tend to learn by rule of thumb in the shop. The productive capacity of the shop will suffer by his more comprehensive training, and alternations between day-rates and piece-rates will have to cover this depreciation of the boy's value to the firm. However, the industry will reap the benefit from the fully trained moulder, and the longer view will justify (1) the necessity to compensate the moulders to take charge of apprentices; (2) paying the apprentice during his periods of inexperience; and (3) encouragement of good trainees by suitable increments in wages for progress made.

Training of Future Executives

During his apprenticeship both the potential executive and craftsman will follow the same course and a sifting of the boys will inevitably take place. At 18 to 20, organising ability, attention to detail, initiative and desire to extend the scope of the instruction will emerge in varying degrees in the different boys. By then the potential executive will have given signs of his particular ability and, whilst the majority will continue a course to produce craftsmen, he will continue a more specialised course designed for an executive or administrative position. Such a course would develop the objective viewpoint, the ability to organise and plan shop routine, a knowledge of metallurgy, costing, piece work and bonus systems, progressing, time and motion study, mechanisation and the economics of modern factory production.

The potential executive then, at 18 years of age, continues his studies at the technical institutions and gains a deeper knowledge of the basic subjects mentioned above. His position in the shop during this time would be that of a type of special moulder, or under-foreman, given work apart from the normal routine—like the leader of an orchestra who is only one of the musicians, but rather a specialised individual. Such courses as outlined above are already working successfully in some British foundries. The completion of his training would involve a year at an institution after the fashion of the British Foundry School, because such specialised training would be beyond the capabilities of the majority of large- and medium-sized foundries or technical colleges. By a proportional pooling scheme amongst the country's foundries, schools for such specialised instruction could be established in the main industrial centres and provide the necessary finishing school for all the future higher executives of the industry.

The rosy and glowing picture painted above is an exposition of the opportunity any apprentice could have, but—and the "but" is a big one—it is necessarily only the absolute cream of the many who will ever attain the final goal of the finishing school. The first year of the craftsman's apprenticeship will see a grading of the new material; some will show early signs of their inability to profit by further instruction, whether by indolence, irresponsibility, lack of mental faculties or sheer inaptitude. These must either join the unskilled operative class or seek their ambition in some other industry. Each successive year will cause a falling off in the numbers who will go forward, and the scheme in operation should provide the foundry industry with the best of all types, labourers, moulders, foremen, metallurgists and managers.

Generalised not Particularised Training

The apprentice should have the run of the shop before settling down to a specified class of work. Apart from developing his skill as a moulder, this is to retain his interest. For instance, the foundry on heavy, medium and light castings needs no investigation from this point of view, but increasing mechanisation and specialisation are tending to direct the industry into mass-production channels, using a higher proportion of unskilled labour confined to one class of work; the light repetition foundries—moulding machines and green sand—for example. Work here is monotonous and fatiguing, variety and scope for learning are limited, yet this industry will also need boys. However, opportunity for learning should be as wide as the class of work will allow, and encouragement to enter and remain in the industry will rest on three points:—(1) This class of work tends to need more executives than the more general foundry, and chances of promotion are proportionately greater. (2) Betterment of working conditions should include rotation of labour (more feasible in light repetition work) and more frequent rest and recreation periods. (3) An impartial time-and-motion standard basis of payment, enabling the operatives to earn a basic living wage without undue fatigue.

Adoption of such schemes as the above will meet opposition from industrialists and employees—one because of the time and money expended for no immediate return, the other through innate conservatism. The industrialist's viewpoint would lack foresight because the increased efficiency and content of his operatives will give him good return from his investment. The employee's objection will fade once the changes have been made and overcome the inertia which keeps him so grooved and inflexible. For instance, rotation of labour already mentioned has been a success in many factories, beneficial both to production and operatives, but the latter raised strong objections at first.

General Conclusions

In this Paper the authors have ignored economics and their close associate, politics. This has necessarily resulted in taking for granted the absence of many aspects which cry for consideration in any Paper on education and industry. Modern manufacturing methods—aptly termed "machinofacture"—have encouraged the use of female, child and unskilled labour, and in these trades the craftsman has outlived his usefulness; there are grades of interlocking specialisation—the rationalisation of industrial processes. This has tended to the casualisation of labour and the anomaly has been found of great unemployment in the 18 to 20 age-group, while industry has complained of a shortage in the 14 to 18 years' group. A machine minder need not serve an apprenticeship and the latter has been replaced by "learnership" agreements—of doubtful long-term value to the industry. A boy, seeking to gratify his ambition, studies and qualifies himself for a better job, only to find it does not exist.

The terrific overall speed-up in production *per capita* has brought many evils in its wake—ennui and absenteeism from sheer monotony, blind-alley jobs, exploitation, death of the apprenticeship system, seasonable occupations and, above all, a rooted distrust in people's minds of those trades most affected by mass-production. These problems are being tackled by employer, employee and the State, and will be solved. In the meantime the educational system can only be planned to suit the better conditions that will prevail and, fortunately, the craftsman still exists in the foundry industry and, until he is no longer needed, there is good reason to make the apprentice interested and capable in his job.

The foundry must be publicised and advertised, as has been suggested for industry in general. The Institute of British Foundrymen, already the centre of external activities connected with the foundry, can do much to recommend the trade; by lectures and films, illustrating the more modern foundries, in schools, technical colleges, etc.; by compiling the advantages and opportunities, with the qualifications and responsibilities attached to the varying grades of employment, in the trade and by supplying, possibly in leaflet form, this information to the education authorities and panels, together with lists of foundries suitable for works visits by students.

Finally, the authors may have said nothing that is new and probably much that may be dismissed as impossible, especially until this war is over. The answer is:—(1) A plan made now can be modified after the war to suit prevailing conditions then, and if a framework is built now, then the initial inertia has been overcome; so much more progressive than leaving till to-morrow the problem of to-day. (2) Industry has voiced a complaint and the causes of that complaint will continue to exist until some of these "impossible" alterations are made.

Acknowledgments

The authors wish to record their grateful thanks to the many colleagues who, by provision of data and patient discussion, have assisted in the preparation of this Paper.

DISCUSSION

MR. S. H. RUSSELL (Past-President of the Institute), opening the discussion, welcomed the Paper as a very valuable contribution, obviously the result of patient thought and careful investigation; much of it, he said, had run parallel with the discussions of the Education Committee of the Institute, and most of the conclusions drawn in the Paper were very sound. Referring to the section of the Paper headed "Past Aspects on Education," he said there was a slight tendency to over-stress the fact that the elementary schools held examinations for children of the age of 11 years in order to sort out those who were suitable to take a secondary education. There was a tendency to conclude from that that the education was designed primarily for secondary school purposes.

With regard to the authors' view that the age of 11 years was too early a stage at which to make a definite decision about segregating children into groups according to their future vocations, Mr. Russell agreed that the problem was difficult; but he believed the educational authorities had agreed that at that first critical stage the decision had to be made, for better or for worse, and it was suggested that there should be some facility later for up-grading or down-grading the children, transferring them to different groups as they developed. The second paragraph, under the heading "Early Education," giving the authors' suggestions concerning the studies of children from the age of 11 onwards, was sound common sense.

Supply of Teachers

Whilst the authors had tackled manfully the problem of the supply of teachers, he did not think they had found a solution; indeed, he doubted that there were an immediate solution. A fundamental problem for all industry in relation to the present education system was that the teacher was in a class apart. He received first the normal academic type of education, and then went to a university; his hours were unusual, he seldom mixed with people outside his own sphere, and he became accustomed to an academic atmosphere, which was disastrous from the point of view of the education and recruitment of young people for industry generally. Mr. Russell believed that that difficulty had become recognised by the Board of Education and the educational authorities generally, but he did not know whether or not they had found the solution of the problem. A good schoolmaster was not trained in two or three or five years; one could not expect him to mature at much earlier than 35 years of age.

Commending the authors' comments and recommendations for overcoming the natural objection to leaving work with the evidence of one's job still upon one's person, he said that perhaps the most striking recommendation was that the marked segregation between staff and operatives should be discouraged. It was always puzzling that the clerical staff should have certain privileges which did not apply to the works' staff. For instance, the clerks enjoyed a fortnight's holiday; but it seemed that the foremen should enjoy that privilege before giving it to the clerks.

Speaking from his own personal experience, and not on behalf of the Education Committee of the Institute, Mr. Russell expressed the view, though he was open to conviction or persuasion, that vocational training in a school was a mistake at any age. He was not referring to the technical schools, but to the part-time schools. Ultimately the aim was for a boy to leave school at the age of 16 years, and then to attend part-time classes two or three times per week for another two or three years. Mr. Russell did not think that boys could be taught close details of the coal-mining industry, etc., at such classes; if of good education, they could learn those things quite well later. Finally, Mr. Russell assured the authors that their Paper would be considered very carefully by the Education Committee.

Educational Ideals

MR. E. H. BROWN urged that the time was overdue to ensure that every child, during his or her last few years at school, should have the opportunity to hear addresses from prominent industrialists who were really competent to discuss the interesting aspects about those industries. Just before the war he had made such arrangements, through the good offices of an enterprising headmaster, but the outbreak of war had frustrated the scheme. His object had been to try to attract suitable recruits to the foundry industry.

With regard to education in general, he recalled that his headmaster, who had been for a number of years the President of the Headmasters' Conference, had often impressed upon the boys at school, and the old boys, his idea of the major difference between elementary and secondary education. It was that elementary education set out to give the facts, whereas secondary education set out only to teach a student how to learn, thus ensuring he would later acquire with facility the specialised knowledge which he would require in the course of his career.

The Financial Incentive

Mr. J. Blakiston did not think the foundry industry in general realised the condition that was arising with regard to recruitment. In almost every foundry the good operatives were men more than 45 years old, and there were very few young men. The only way in which to attract new recruits to the industry was to provide a financial incentive; although that sounded rather crude, it was a fact which must be faced. Although the foundry trade was paid slightly higher than some of the other engineering trades, either it was not paid sufficiently highly or it was conducted under conditions so unattractive that they turned people away from it before they realised its advantages—and the foundry trade had many advantages because it was adaptable. It was able to cope with many situations. When the basic industries were busy, the luxury trades were sometimes slack, and sometimes the luxury trades were busy and the basic industries were slack. The foundry catered for both.

It was rather disappointing that no reference was made by Mr. Harbach and Mr. Horton to an excellent Paper read by Dr. Douglas H. Ingall at the Middlesbrough Conference of the Institute in 1930, in which he had described a foundry apprentice training scheme of considerable extent which he had put into practice. Mr. Blakiston said he believed that that scheme was still in operation, and that the industry was indebted to Dr. Ingall for a large number of excellent recruits in foundries scattered all over the country.

The Next Phase

Mr. J. C. Charlton expressed his appreciation of the authors' excellent work, and pointed out that a new Education Bill was to be introduced in Parliament soon and he asked what steps it was proposed to take to bring into operation any scheme the industry or the Institute might prefer. The numbers and quality of foundry apprentices were lamentably low at the present time and something should be done to attract more and better boys to the foundry trade. Education was one way to improve the boys before and after entry into the foundries and conditions generally could be improved. How was it possible to translate ideas into practical politics? He hoped the Education Committee of the Institute would know how to help in that direction.

The President said the Education Committee had spent about 3½ hours on the previous day discussing the problem which Mr. Charlton had expressed so concisely. They were exploring every avenue, and any help which members of the Institute could give to the Education Committee would be welcomed. If any members had suggestions to make as to how to approach the various authorities, he would be glad if they would communicate those suggestions to the chairman of the Committee.

Employer Collaboration

Mr. Russell said that there was one very promising avenue of approach through the Council of Ironfoundry Associations upon which the I.B.F. was represented. The avenue of approach through the trades unions had not yet been explored.

Mr. Williams urged that there was another way of encouraging youths to enter the foundry industry than by reference to financial considerations. It was true that some youths were attracted by money, but there were others who had a well-developed sense of duty.

Mr. W. T. Hodgkinson drew attention to the point that sometimes the recruits to the foundry industry were of poor quality simply because they had entered the industry by reason of their inability to get other jobs. Some had started to train for electrical and mechanical engineering, and so on; and when they could not find jobs in such industries, they accepted any job they could get. Thus, their training had to be switched over. Endorsing the view that prospects of good pay were necessary in order to attract recruits to any industry, Mr. Hodgkinson complained that the trouble in the engineering industry had been due to the fact that at about the year 1930 the skilled mechanic had received only £2 12s. per week, whereas local authorities were paying £3 per week for road-sweepers.

Mr. J. Blakiston commented that it was necessary to glamorise the foundry industry!

Widening the Field

Mr. M. Seaman said that his company* had considered very closely the problems of education and recruitment. He did not think the foundries ought to consider the education problem purely from the point of view of foundries, but rather as part of the whole business of engineering. For some years he had been closely concerned with the electrical and mechanical sides of engineering, and consideration had been given to the interests and problems of the young men at every stage, right up to the final executive positions. In his discussions with foundrymen he had found that many were considering merely the entry of young men to the foundry as moulders or coremakers, or as operatives in some other capacity on the foundry floor; then they were worried because boys preferred the cleaner trades, such as electrical and mechanical engineering.

The point about glamorising the industry was a very good one. It was of little use to show a boy the foundry floor and to say that he would be employed there; a boy should be shown the whole picture—which was a very good one—so that he would appreciate the real need for sound scientific and practical men in the industry. That should be the line of approach.

Urging that whatever was done by the Institute should be geared into the organisations inside the various firms, Mr. Seaman said the executives could all direct their own concerns, but at the same time they should try to work jointly with the Institute and its associated bodies. If it were done nationally, with proper co-operation, there would be real progress. It was probably the most important work in the foundry industry at the moment; and the authors of the Paper were to be congratulated on having started further fruitful lines of thought.

Author's Reply

Mr. Horton, in a brief oral reply to the discussion, said that the view put forward by Mr. Brown (quoting his schoolmaster) that elementary education set out to give the facts, whereas secondary education set out to teach a man how to learn, was sound commonsense, so long as the secondary school boys were so trained that they were able to learn on a practical plane. It was true that they were taught how to learn; but were the subjects such that when they left school they could continue to learn on a different plane in industry? He had found a great difference between the academic atmosphere and the industrial atmosphere in which one was told what to do and how to do it, in no uncertain terms!

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* Newton Chambers & Company, Limited.

After assuring Mr. Blakiston that he would study the foundry apprentice training scheme described by Dr. Ingall, Mr. Horton said that the Paper now before the meeting had been written because a new Education Bill was to be introduced into Parliament; inasmuch as educational reforms were imminent, it was hoped that full consideration would be given to the needs of the foundry industry before the Bill was launched. Finally, in reply to Mr. Charlton, he said that Mr. Russell and the Education Committee were more capable than himself of deciding the best means by which to ensure that the needs of the foundry industry were met.

Continuity Severed

MR. R. F. COATES wrote that he had read the Paper on "Industry and Education" with both interest and profit, and considered it most encouraging that the matter had reached the stage when the Institute regarded it of such importance as to invite the authors to present the Paper at the Annual Conference. The Paper outlined in a practical manner a basis upon which a sound system of industrial education could be built. With regard to the foundry apprentice, the writer considered that all technical training should be given during the working hours.

Those who had served an apprenticeship in the foundry knew from their own experience that, after a day's work, a lad was not in a condition to gain the full advantage of evening instruction. As the industry desired to produce craftsmen, piece-work should be discouraged among apprentices and a merit bonus system would tend to induce the apprentice to put quality of work before quantity.

It was interesting to note that, particularly in the foundry industry, very few of those who had experienced the rigours of the foundry apprentice, encouraged their own sons to follow their trade. This was not as it should be; for was it not a strong trait in British national character that son should follow father in trade or profession? Moreover, did not the fathers have some pride in knowing that their sons were carrying on their vocation?

Again, was not the father able, when a son was following the same calling, to supplement the lad's training from his own experience, personal interest, coaching, etc., which in so many cases produced a higher degree of skill in the son which ultimately benefited the industry? This somewhat unhappy state of affairs might to some extent be due to the son desiring more congenial work, and the father knowing from his own experiences that he would have chosen another calling, had he his time over again.

As pointed out in the Paper, moulding will never be a "collar and tie" job; but as the older foundries give way to the new, conditions therein will undoubtedly improve. Much would be done in existing foundries to improve working conditions and general appearance by "good housekeeping," and much more when happier days return. It was to be hoped that the seed that the authors had taken and selected would, in the very near future, germinate in the form of definite co-operation by all parties concerned, and this would result in united action to equip our industries with qualified personnel.

The Descriptive Phase

MR. E. J. KELLY wrote that in the post-war planning of industry, education would play a very important part. The authors had therefore performed a most useful and timely service with a review of the history of the educational system of the country in relation to industry.

Many who were interested were agreed that the facilities for technical training for those about to enter industry left much to be desired. This was particularly true of the founding industry, and much could be achieved on the lines set out by the authors.

It was necessary that those interested should put forward their schemes and suggestions now (for many they will be), so that a governing body be set up to determine a definite principle for instruction. Much useful work had been done by the various education authorities, founding firms, and institutions, including the Institute of British Foundrymen, to advance the scientific and technical training of founding personnel. Many of the technical colleges throughout the country had introduced classes in foundry science and practice, the students being prepared for the City and Guilds examination.

The syllabuses and regulations adopted on the recommendation of the Advisory Committee of the Institute of British Foundrymen, with which the City and Guilds of London Institute co-operates, formed a very sound basis for the training of future foundrymen. Nevertheless it was the education and training which the boy received prior to entering industry that chiefly concerned those interested at the present time.

Junior technical schools were suggested for post-war planning, and, providing the school-leaving age was raised to 15, there was no reason whatever why a boy should not receive between the ages of 13 and 15 a course of instruction in foundry science and practice, at one of these such schools. The training should be descriptive wherever possible, augmented by works' visits; also that foundry executives visited the schools and gave the students the benefit of years of experience, by talks and practical examples, to assist them in becoming first-class craftsmen; and the more successful ones to go forward to fill the higher positions in the industry.

The fact that only a very limited number would attain the final goal of the finishing school applied equally to all other sections of industry. The effort was efficiency in all grades of foundry personnel in whatever capacity employed. That many non-foundry trained people were placed in charge of foundries only proved the greater need for technical training of those entering the industry, so that those who served might have an opportunity to lead or govern.

The need for improving foundry conditions generally was apparent to all, and sustained effort must be made to effectively achieve this end.

Authors' Written Reply

MR. G. L. HARBACH, on behalf of both authors, wrote that Mr. Russell had stated that 5 years was insufficient to train a good schoolmaster, and they agreed that the necessary blend of tact, justice, psychological ability, even temper and knowledge, which went to make a good schoolmaster could not be instilled in such a short period. They felt, however, that there must be available in industry many thousands of administratives and executives, already possessing these qualities, who, if not already efficient spare-time teachers, only needed a short course to develop confidence in their ability to impart knowledge.

Mr. Russell's personal antipathy to vocational training in schools was heartily reciprocated, if, by vocational it would be assumed he referred to specialisation in a specified trade. It was stated in the Paper that the aim was not to turn out a fully-fledged entrant into industry, but rather someone whose brain and body had received training to prepare them for the change from school to industry.

It was agreed that the financial incentive as suggested by Mr. Blakiston would make an immediate appeal, but the survival of a healthy industry cannot rest entirely on this, at least, not while men still possessed a measure of self-respect and the opportunity to earn equal money in more congenial surroundings. The authors had referred to Dr. Ingall's Paper, and particularly agreed with his remarks on the necessity for close co-operation between industry and the Technical Colleges. His good work in connection with the Constantine College was well known in the foundry world, and the scheme, as now in operation, was well worthy of consideration when formulating plans for the future.

The authors thanked Mr. Charlton for the very pertinent query raised in his remarks. Discussion of how to encourage action on the subject of the Paper was omitted because the authors considered that this, probably the most difficult task, was a question requiring the consideration of a qualified body of opinion, such as the Institute's Education Committee.

In their rough analysis of any proposed educational reform the authors endeavoured to point out the necessity to avoid considering the question from the foundry viewpoint alone, as was suggested by Mr. Seaman. As to glamourising the industry, the authors fully agree, always with the proviso that in using the word "glamour," there was no intention to falsely depict certain aspects of the industry in order to gain advertisement value. Co-operation with the internal organisations of different firms already tackling the problem would undoubtedly help to establish any reforms on a national basis, and ensure that the industry progresses as a whole irrespective of individual improvements.

That foundry personnel should discourage their own sons from following them, emphasises the present unhealthy state of the foundry trade. The disappearance of this tendency will not only materially aid the industry to produce better craftsmen as indicated by Mr. Coates, but will also be one of the first signs that the present problem is approaching a satisfactory solution. Technical training should be given during working hours, and the authors understood that the Minister of Education intended to make such part-time systems a compulsory measure.

Mr. Kelly stressed the importance of making any attempts at vocational instruction as descriptive as possible, with works visits and members of industry to give lectures. This would retain interest, encourage enthusiasm, and at the same time provide a direct appeal to the leanings or preferences a boy may have towards any particular trade.

In conclusion, the authors of the Paper wished to express their thanks for the appreciation and interest shown by members of the Institute in the written and verbal discussion.

Paper No. 774

Hot Tear Formation in Steel Castings

By CHARLES W. BRIGGS*

[*American Foundrymen's Association Exchange Paper*]

It occasionally happens that in the manufacture of steel castings, defects in the form of cracks are found. These cracks have a very irregular and jagged appearance, and as the fracture face is quite oxidised and shows a heat effect, these cracks are known as hot tears. The steel casting industry in America is very much concerned about the presence of hot tears and an extensive amount of non-destructive testing is carried on to make certain that steel castings are free from this defect.

Considerably more is known regarding the hot tear type of defect because of the general use of non-destructive testing in the steelfoundries. Steel casting purchasers, such as the United States Navy Department, have radiographic standards for steel castings which illustrate examples of hot tears and advise that their presence in any form is cause for rejection of high-pressure valves and fittings, turbine casings, steam chests, low-pressure valves and machinery castings subject to fatigue or impact stresses. Such castings may be repaired if defective from hot tears, providing that the area is further radiographed and subject to radiographic standards for welding. Practically all steel foundries that produce castings for high-pressure, high-temperature equipment, important ship and ordnance castings, have available radiographic equipment for examination of pilot castings and for use as means of final inspection.

Testing Equipment

It would seem of interest to briefly review how steel casting producers are set up to find hidden internal hot tears and those tears that come to the surface. Five steelfoundries have the million-volt X-ray units, 15 additional foundries have industrial X-ray units of varying voltage of smaller than the million-volt units. Eight foundries own radium for industrial radiography. Approximately 150 steelfoundries have rented or purchased radium for industrial radiography and, at the present time, there are over 75 steelfoundries participating in yearly leases. Also, the U.S. Navy owns about 17½ grammes of radium for inspection of steel castings. The radium capsule usually used will contain from 100 to 500 milligrams of radium sulphate.

Thus, it will be seen that over 50 per cent. of all steelfoundries in the United States have had experience with either gamma-ray or X-ray radiography for the study of casting technique and for use as an inspection requirement.

Magnetic testing is also being used by steelfoundries for the location of surface crack and external hot tears. There are approximately 30 to 40 steelfoundries that have available magnetic testing equipment to be used in the inspection of steel castings. Generally speaking, the steel-casting industry favours the use of gamma-ray radiography, because of the portability of radium, its wide latitude in radiographing varying sections and radium can be obtained on a rental basis.

The above points are brought out, even though it is a deviation from the subject to be discussed, because non-destructive testing is accomplishing so much toward the understanding of the hot tear problem. From various practical considerations and from certain experimental observations, it has been established that hot tearing takes place at a temperature not greatly below the solidifying temperature of steel.

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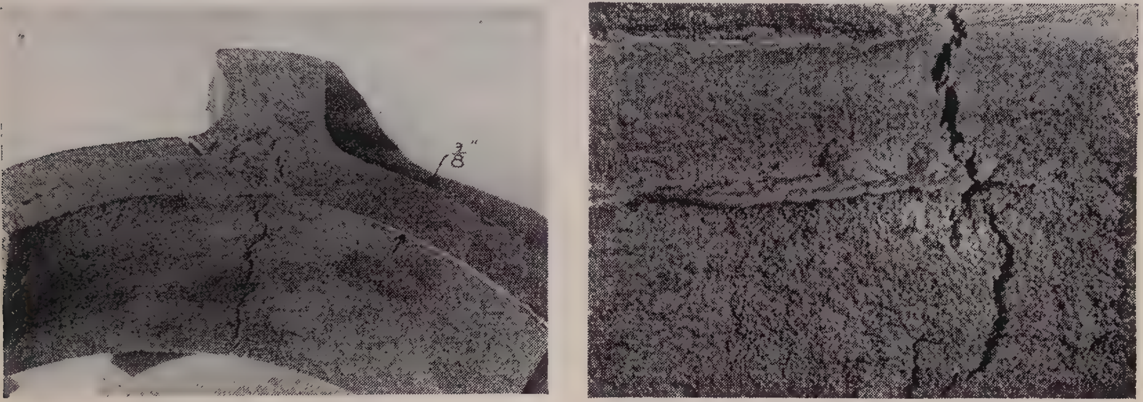
* Technical and Research Director, Steel Founder's Society of America, Cleveland, Ohio.

Types of Hot Tears

Because of the general occurrence of hot tears they have been divided into two groups[1]:—(1) External hot tears; and (2) internal hot tears.

The external hot tears are so-called because the crack defect can be plainly seen on the surface of the casting. The crack first opens on the surface of the casting and proceeds inward. Such a crack has the appearance of a tear; that is, the face of the crack is ragged. The crack is wider at the surface and is uninterrupted in depth and in some cases may traverse the entire section (Figs. 1A and 1B).



(a) In a small casting.

(b) In a large casting.

FIG. 1.—EXTERNAL HOT TEARS IN A STEEL CASTING.

The cracking or the failure of such a casting could be considered comparable to the failure of a test specimen under load at a high temperature; the cracking begins at surface irregularities, sharp corners, changes in section, and the like which serve as points of stress concentration. The stresses active in their formation appear to be tensile or shear stresses.

The internal hot tears (Figs. 2 and 3) are found near the centre of the section, or that portion of the section where there is a pronounced hot spot or where solidification takes place last. They are of a decidedly ragged nature, usually with branches. They have no definite line of continuity and nearly always exist in groups. These tears seldom terminate at the surface; in fact, most of them do not. When they do appear at the surface, they are usually very small and difficult to locate. Upon exploring them downward, they will be found to branch out and become more pronounced.

The internal hot tears are regarded as the most dangerous type, since they may be present in a section the surface of which is without defects. Their presence is not realised until they are uncovered by machining or disclosed by radiographic examination. In some cases they have been treated with indifference, the attitude being that what cannot be seen cannot be considered as harmful. However, it is well substantiated that internal hot tears present in a casting in service may extend until they traverse the section. In so doing they render the casting unserviceable, for example, a pressure casting.

Occurrences of External Hot Tears

Hot tears occur because the casting, or a portion of the casting, is under stresses of sufficient magnitude to cause cracking to take place. The presence of the stress is due to the design of the casting, the manner in which the casting cools, and the construc-

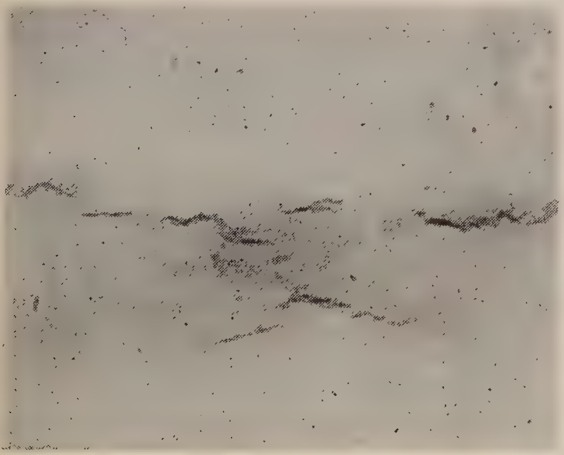


FIG. 2.—RADIOGRAPH OF INTERNAL HOT TEAR IN A 2-INCH SECTION OF A STEEL CASTING.

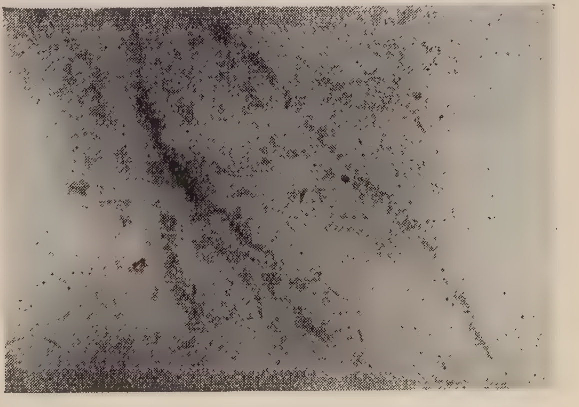


FIG. 3.—RADIOGRAPH OF INTERNAL HOT TEAR. TEAR IN SECTION IS APPROX. 4 INS. THICK AND EXTENDS ABOUT 3 FT. WITHOUT COMING TO EITHER SURFACE OF THE STEEL CASTING.

tion of the mould. Stresses arising from any one of these conditions may be sufficient to produce hot tears.

Internal stresses in a casting are proportional to the modulus of elasticity of the cast steel to its coefficient of contraction and to the difference of temperature involved within the casting. Since the modulus of elasticity decreases with increasing temperature, the magnitude of the stresses necessary to cause permanent deformation and permanent stresses in the casting also decreases. Also, a steel has a relatively high coefficient of contraction and the temperature gradients present in a casting may be quite high. Thus, high stresses are a probability.

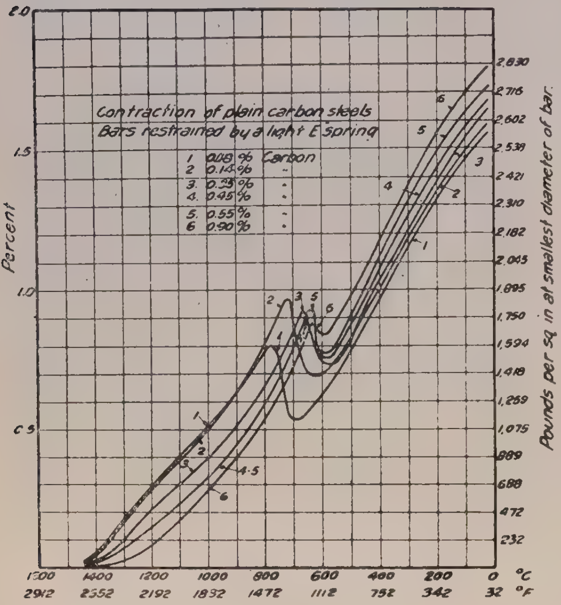


FIG. 4.—LIGHT HINDERED CONTRACTION OF PLAIN CARBON STEEL.

As steel cools from its solidification temperature to room temperature, it contracts. If it is allowed to contract freely it will have a volumetric contraction of 7.2 per cent. for a 0.30 per cent. carbon cast steel. which is a linear contraction of 2.4 per cent.[2] Steel castings, however, do not contract this amount, due to their shape and the fact that the mould material in which they are cast acts to restrain the contraction tendency. The normal patternmaker's shrinkage of 1.87 per cent. which is used in the construction of patterns is in itself a value of hindered contraction. Some castings may be produced with only a total linear contraction of 1 per cent. or even less.

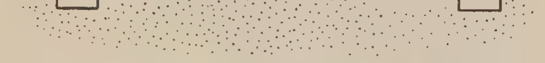


FIG. 6.—BAR WITH FLANGES.

It has been established (Figs. 4 and 5) that as the total linear contraction taking place in the solid state is reduced, the stresses acting on the casting increase.[2] If for comparative purposes it is considered that the amount of stress present on a casting at 2,000 deg. F. (1,093 deg. C.) to be 875 lbs. per sq. in. for a total contraction of 1.65 per cent., then at 0.95 per cent. contraction the stress would be approximately 1,050 lbs. per sq. in. In other words, hindered contraction increases the stress acting on the casting. Castings may be hindered in their contraction by:—(1) The resistance of the mould; and (2) by the shape and form of the casting.

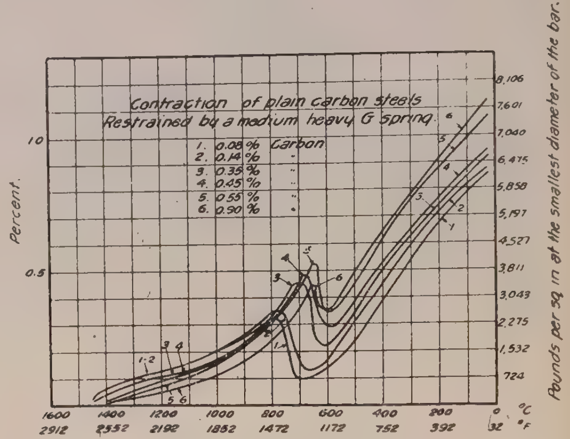


FIG. 5.—MEDIUM HINDERED CONTRACTION OF PLAIN CARBON STEEL.

The manner in which mould conditions operate to cause internal stress has been described in technical writings dealing with the design of steel castings. There is sufficient evidence to point out that internal stresses arise due to the prevention of normal contraction by the rigidity of sand moulds and cores. A simple example will suffice. Fig. 6 represents a hard dry sand mould of a bar with flanges on both ends. It is evident that the sand between the two flanges will prevent the cooling bar from contracting normally. The bar tends to contract toward its centre, but the sand pressing against the inside faces of the flange prevents it from so doing, and hence stresses are built up in the casting as the casting

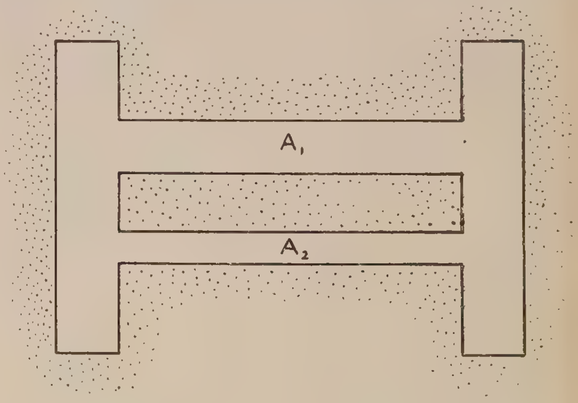


FIG. 7.—TWO BARS JOINED BY FLANGES.

cools, the bar portion being under a tension stress.

In all probability an external hot tear will form at the junction of the bar and flanges. The reason that the casting tears at these points is that the tension stresses that are developed in the bar by the flanges will concentrate at the weakest section, which in this case is the junction of the flanges to the bar. The stresses developed were sufficient to exceed the mechanical properties of the metal at that particular temperature and hot tears were formed.

The location or position of hot tears are nearly always at points of design weakness such as at re-entrant angles, the joining of sections, or in sections made weak by the presence of hot spots. Hot spots, of course, are sections of extra mass usually found at junctions of joining sections. Thus, if hot tearing occurs, it will be at the weakest section, which presumably will be the hottest section.

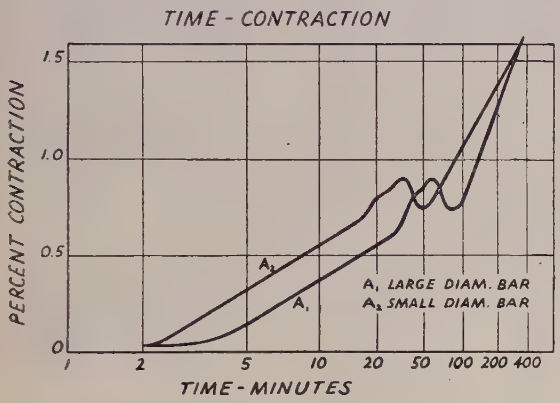


FIG. 8.—TIME-CONTRACTION CHARACTERISTICS OF BARS OF DIFFERENT SIZES, NOT JOINED TOGETHER.

It has also been stated that hot tears result due to the shape or design of the casting. This point is illustrated by Fig. 7, showing a design of two bars with flanges, wherein a large bar of cross-section A_1 is joined to a small bar of cross-section A_2 by heavy end sections. Bar A_2 will completely solidify before the large bar A_1, thus a temperature gradient is produced within the casting. This temperature gradient is responsible for a setting up of stresses in the casting since the amount of solid contraction depends on the temperature and the hindered contraction.[5] The internal stresses created by these temperature gradients are so great, in this case, that the elastic limit of the material is exceeded. To exceed the elastic limit is not a very difficult condition to fulfill, since steel at very high temperatures has low elastic limits and all deformation taking place is principally plastic.

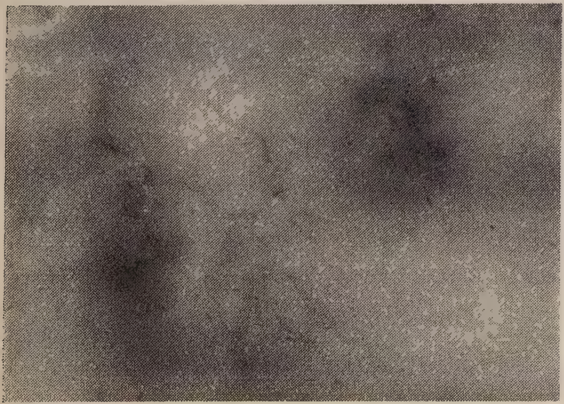


FIG. 10.—RADIOGRAPH OF AN INTERNAL HOT TEAR IN A STEEL CASTING.

The mould chilling effect and the variation in cross-sectional areas of the two bars cause the wide difference in temperature. Since the contraction of the steel is closely aligned with the temperature, the normal rate of contraction of the two bars will be somewhat different. A possible condition that may exist is shown in Fig. 8. The data plotted here represent that time-contraction characteristic of each bar separated instead of being joined together by the flange construction. The most noticeable variation comes shortly after the steel has solidified. Evidence exists that there may be temperature gradients as much as 350 deg. F. in a casting of intricate design.

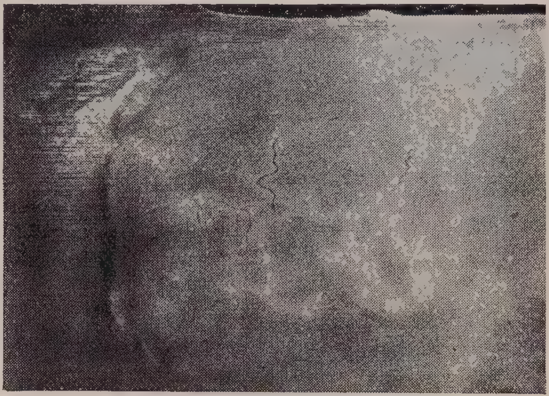


FIG. 9.—INTERNAL HOT TEARS BROUGHT TO THE SURFACE BY MACHINING A STEEL CASTING.

Since the two bars are tied together they cannot contract as shown in Fig. 8, but will take an intermediate course, and the small bar will be in tension and the large bar in compression with the stresses mounting as the temperature drops. At some temperature the stress acting on the casting is greater than

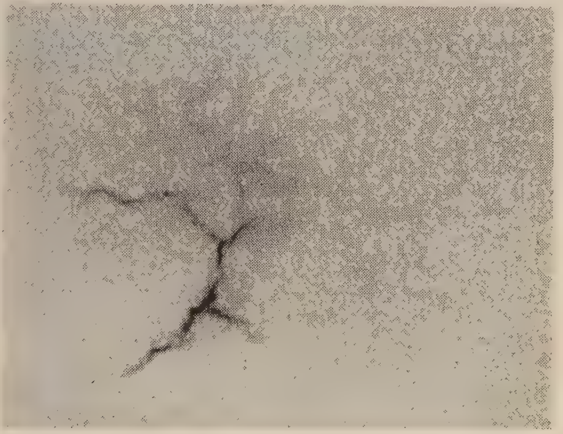


FIG. 11.—RADIOGRAPH OF AN INTERNAL HOT TEAR RESULTING FROM SOLIDIFICATION CONTRACTION.

the properties of the steel, and the casting fails from hot tearing. The tears in this case will probably be found at the junction of the small bar and the flange, since the small bar is under tension stresses and the junction is a weak spot and a position of concentration of stresses.

Thus, when steel is cast under conditions that tend toward high resistance to contraction, either because of mould resistance or casting design, the magnitude of the stresses acting on the casting is high, the rate at which they build up is fast, and the possibility of hot tear formation is great.

The Occurrence of Internal Hot Tears

Internal hot tears are the result of two effects: (1) Conditions similar to those causing external hot tears, that is, prominent temperature gradients which cause solidified sections to pull away from partially solidified sections or completely solidified sections at a higher temperature (Figs. 9 and 10), and (2) solidification contraction, which because of insufficient feed metal may result in the formation of hot tears in a section instead of the usual shrinkage cavities (Fig. 11).

Internal hot tears are caused by stresses built up by temperature gradients. The same stresses that cause external tears, only in this case, the tears start at a location near the centre of the section and extend outward. The reason the tears do not come to the surface of the casting is that the skin of the casting is at a lower temperature and is able, because of its higher properties, to withstand hot tear formation.

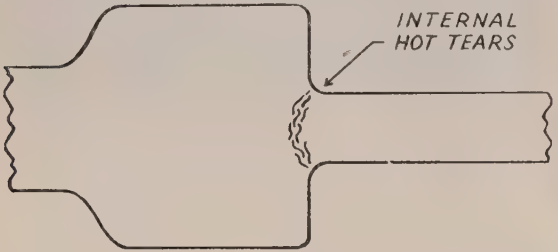


FIG. 12.—FORMATION OF INTERNAL HOT TEARS AT A POINT OF STRESS CONCENTRATION.

During the solidification of a section and for a short period thereafter there is developed quite an extensive gradient between the skin temperature and the temperature of the centre of the section. Thus, the skin, being cooler than the centre, is able to withstand greater stress loads. If it is recalled that one section of a casting may be contracting faster than another, and the design of the casting is such that it is an enclosed stress active system, then it is easy to see that tearing may take place in the weak central section of a casting at points of stress centralisation without those cracks coming to the surface (Fig. 12).

It is also quite possible that this tearing may take place at temperatures greater than that found when external hot tear occurs. In fact, it may take place during the solidification of the casting. At least Singer and Bennek[5] have found it so, for they have shown how internal hot tears in the solidified portion of the casting can be subsequently filled with fluid steel in the unsolidified central portion of the section. Such conditions have been found elsewhere, such as is shown in Fig. 13. Also, the tears are of such a shape and of such random distribution that it is evident they occurred while the steel possessed very low mechanical properties.[6]

It is also quite possible that mould resistance may play a part in the formation of the internal hot tears. This is a point that cannot easily be proved or disproved. However, because of the internal hot tears close proximity to abruptly changing sections, it is believed that the action of temperature gradients in the formation of stresses is the more important.

It has been suggested that solidification contraction may be responsible for hot tear formation. Failure to allow for sufficient molten metal to provide for the steel contraction in volume at the time of its solidification is the reason for the occurrence of these types of hot tears, such as shown in Fig. 11. In uniform sections and in isolated sections the cavities that normally may form, may form instead as tears radiating out from small cavities, since the contraction of the metal toward the solidifying centres is sufficient to create a stress that tears the last solidifying metal. This stress need not be large, as the metal as it solidifies must be in any case very weak.

There is a difference of opinion in the United States as to the correct terminology of hot tears formed because of solidification contraction, and there are those who would rather call such defects "internal shrinkage." Since they look like tears, and since it is the desired aim to make this report all inclusive, they will be treated here as a form of internal hot tears. Which of the two types discussed is the more important in the formation of internal hot tears is difficult to say. All that can be done is to bear in mind that both are effective. The stresses that cause them are apparently tensional ones.

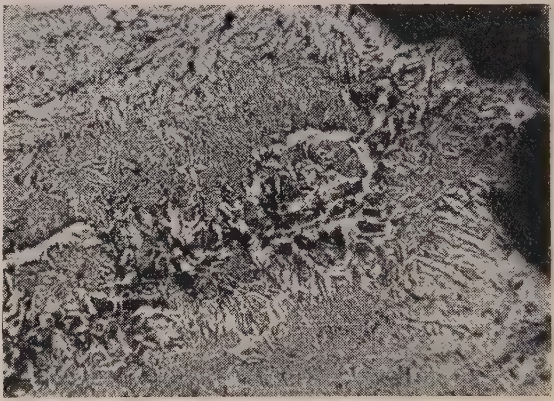


FIG. 13.—HOT TEAR SUBSEQUENTLY FILLED WITH MOLTEN STEEL. (U.S. NAVAL RESEARCH LABORATORY.)

Strength of Steels at Hot Tearing Temperatures

It has been stated that hot tears form at high temperatures. What are these temperatures? What are the mechanical properties of cast steel at these temperatures?

Prior to 1928 much had been said concerning hot tears and how to prevent them, but little was known of the actual conditions of hot tearing, such as the cracking temperature or the magnitude of the stresses causing hot tearing. In 1928, Körber and Schitzkowski[7] produced hot tears in flanged bars by hindered contraction and decided that the critical temperature at which hot tears are most liable to be formed was about 2,300 to 2,400 deg. F. They did not, however, measure the stresses on the bars at the time of hot tearing. In 1932 and 1934, Briggs and Gezelius[2, 8] made a study of the stress acting on a bar during hindered contraction. These bars did not break under the hindered contraction applied, as they were so designed as to prevent points of stress centralisation. Since the bars did not break, this work did not show the actual amount of stress necessary to cause hot tears at the hot tearing temperature, but it did show the load-carrying ability of steel under hindered contraction.

In 1936 and 1938, Hall,[9, 10] of Woolwich Arsenal, presented data on the strength and ductility of steel at temperatures near the melting point. In the region of 2,300 to 2,400 deg. F. he showed that the ultimate stress necessary to cause failure in 1-in. bars averaged, for cast carbon steel, from 1,700 lbs. per sq. in., at 2,370 deg. F., to 2,500 lbs. per sq. in. at 2,280 deg. F. There is no indication from this work that the temperature range of 2,300 to 2,400 deg. is more conducive to the formation of hot tears than any other temperature range. In fact, the temperature-ultimate stress curves show nearly a straight-line relation, in that there is practically a uniform increase in the ultimate strength as the temperature drops.

In Fig. 14 there are presented curves showing the strength of different carbon cast steels at elevated temperatures.[9] The curves indicate that the increase of strength with the decrease of temperature is nearly a straight-line function, and that the lower the carbon content the greater is the strength at any given temperature. There does not appear to be much difference between the values of the 0.25 and 0.42 per cent. carbon curves. This apparently indicates that, as the carbon content increases, the strength differential diminishes rapidly. It would appear from these curves that the higher the temperature, the lower the tensile properties, and hence the easier to obtain hot tear formation.

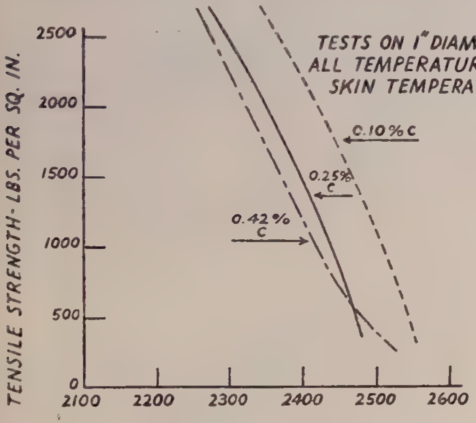


FIG. 14.—STRENGTH OF CARBON CAST STEELS AT HIGH TEMPERATURES.

The elongation values of the different carbon steels at the high temperatures is presented in Fig. 15. The curves show that as the carbon content increases the ductility decreases for any particular temperature. Also, the greatest differences in ductility occur at the lower carbon content. An interesting point is, however, presented by these curves, namely, that for the carbon contents normally produced in commercial practice (0.20 to 0.40 per cent. carbon) the ductility is very low until a temperature of approximately 2,350 deg. F. is reached in the cooling cycle.

Since there is little or no ductility in normal content carbon steels until a temperature of 2,350 deg. F. is reached, then only a small amount of deformation is necessary to be responsible for hot tear formation. Also castings that have failed because of hot tears exhibit sections the fractures of which show no evidence of plastic deformation.

Ductility is, therefore, a very important property in hot tear occurrence. It may be even possible to go a step further and state that it appears that the property of ductility is more important than strength in the consideration of hot tear formation. If this is so, then temperatures can be fixed below which hot tear formation will probably not take place. For carbon contents of 0.25 to 0.40 per cent., temperatures of 2,350 to 2,300 deg. F. would constitute the lower range of hot tear formation. Hot tears, therefore, may form at any temperature between these temperatures and the solidification temperature of the steel.

Because of the increased ductility of low-carbon steels (carbon contents below 0.20 per cent.), the range of hot tear formation would be smaller by approximately 200 deg. F., in that ductility values have reached an appreciable figure at 2,500 to 2,550 deg. F. This would allow an approximate temperature range of only 175 to 225 deg. F. for hot tear formation for a 0.10 to 0.15 per cent. carbon steel, while for the 0.25 or 0.42 per cent. carbon steel a range of approximately 325 deg. F. is available for hot tear formation. This, of course, applies to 1-in. dia. sections, and all temperatures recorded are skin temperatures.

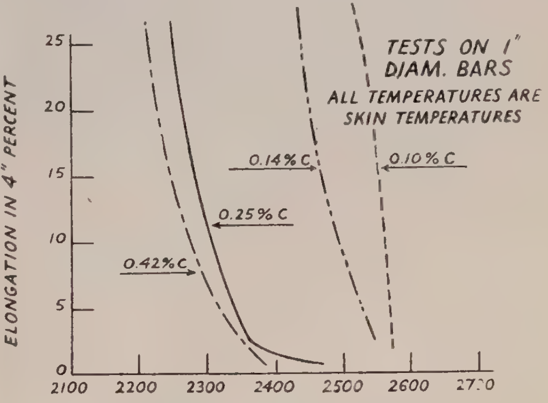


FIG. 15.—DUCTILITY OF CARBON CAST STEELS AT HIGH TEMPERATURES.

Variations in temperature between the exterior and interior of a section brings up another point regarding the strength and ductility of cast steel at high temperatures. In steel castings that solidify and cool in the normal way a temperature gradient exists between the temperature of the skin and the temperature of the centre of the bar. It is, therefore, necessary, when reporting property values, that either the skin temperature or the centre temperature must be used in plotting the results. The temperature is responsible for the recording of different values if different size bars are used in the test studies. Since the skin is at a lower temperature than the centre of the bar, and since the lower temperature steel shows the higher property values, it must follow that the ratio of the area to the circumference of the bar is important in the magnitude of the values obtained.

This point is fairly well substantiated in Fig. 16, which shows the properties of 0.25 per cent. carbon cast steel as tested by Hall[9] on a 1-in. dia. bar and as obtained by the author on a $1\frac{13}{32}$-in. dia bar. This ratio on the two bars is as follows:—

Diameter.	Area.	Circumference.	Ratio.
1 in.	0.79 sq. in.	3.14 in.	0.25
1 $\frac{19}{32}$ in.	2.00 sq. in.	5.00 in.	0.40

From these figures it would appear that, as the area increases with respect to the circumference, the effect of the skin on the test values is not as pronounced. The curves of Fig. 16 tend to prove that this condition actually exists.

The reason for discussing this point is that when mention is made of the magnitude of stresses at the hot tearing temperatures, it will not be necessary to develop stress forces equal or greater than the tensile strength values as set forth in the results presented by Hall. In fact, the strength of a 1-in. section in a casting whose width was greater than 1 in. would be less than the values shown by Hall since the ratio of area to the circumference increases as the width increases. This condition is also true in section thicknesses that are greater than 1 in.

Magnitude of Stress Due to Hindered Contraction at Hot Tear Formation Temperatures

It is known[2] that a 0.35 per cent. carbon steel in the temperature range of hot tearing (2,630 to 2,300 deg. F.) will develop stress loads under various types of hindered contraction, as shown in Table I. These figures would tend to indicate that even under the most drastic conditions of hindered contraction, the stresses developed during the hot tear formation temperature interval would not be sufficiently high enough to cause failure if the values of Hall are used as a basis of comparison. It will be remembered that he showed values in the neighbourhood of 2,000 lbs. per sq. in. as the tensile strength of medium carbon steel at 2,300 deg. F. for a 1-in. dia. bar. But it is known that castings do tear at these temperatures, and as has already been pointed out, sections in castings will not exhibit these high strength values.

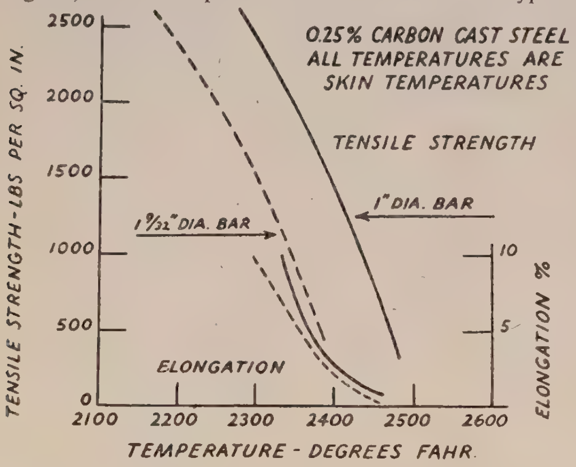


FIG. 16.—EFFECT OF SIZE OF TEST-BAR ON THE STRENGTH AND DUCTILITY OF CARBON CAST STEELS AT HIGH TEMPERATURES.

Tensile strength values at elevated temperatures of medium carbon cast steel that had previously cooled to room temperature has been reported[11] to be 250 to 230 lbs. per sq. in. at 2,250 deg. F. These figures are more in line with the stresses developed by hindered contraction, but it is felt that not too much significance should be placed on these figures since the temperature gradients usually found in steel castings were not present. There is one thing that should be pointed out, and that is, the rate of testing used was much slower than that used by Hall, and therefore more in line with the rate at which hindered contraction stresses are built up.

Even though the tensile values that Hall shows are not applied to practical application, the actual values of casting section strengths at high temperature are undoubtedly still greater than the amount of stress developed by hindered contraction at the same temperature. The realisation of this fact requires that a further consideration be made, namely, that stress concentration is responsible for the apparent discrepancies so that tearing does occur in accordance with practical observations.

TABLE I.—*Stress Quantities at High Temperatures.*

Stress, lbs. per sq. in.			Type of hindered contr.	Per cent. Contr. at room temp.
2,500 deg. F.	2,400 deg. F.	2,300 deg. F.		
105	210	340	Light	1.7
335	500	625	Medium	1.0
385	560	730	High	0.5

It is quite possible that with the differential cooling of a casting, and because of hindered contraction due to mould resistance, stresses will concentrate at a hot spot in the casting, with the result that the casting will tear. The hot spot may have a temperature approaching 2,500 deg. F., while other parts of the casting will be at temperatures of 2,250 to 2,300 deg. In such a situation stresses of 250 to 500 lbs. per sq. in. could arise through hindered contraction, which if concentrated at the 2,500 deg. F. hot spot would be, even according to the high values reported by Hall, a stress load sufficient to cause hot tearing.

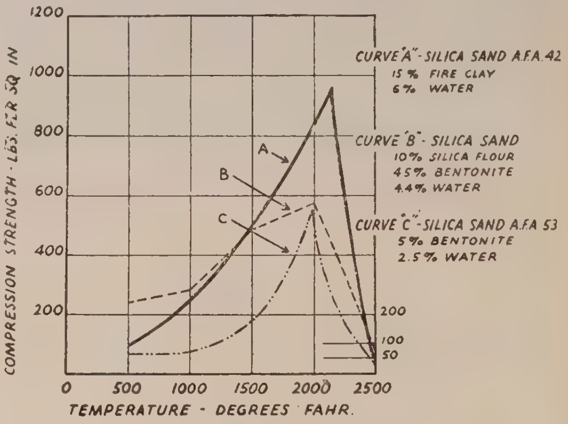


FIG. 17.—THE HOT STRENGTH OF VARIOUS SAND MIXTURES.

Thus, it is possible that small tension or shear stresses as developed by hindered contraction are responsible for hot tear formation, providing that the hindered contraction present is greater than that normally allowed under "patternmaker's shrinkage."

Hindered Contraction Stresses Produced by Sands and Cores

It is quite easily seen that casting design can be responsible for the stresses shown in Table I, which is a brief summary of the results found by Briggs and Gezelius.[2, 8] But what is perhaps more difficult to understand is that sufficiently high stresses can be set up through hindered contraction due to sand mould and cores, and thereby causing hot tear formation. It can, however, be demonstrated that sands and cores can provide, at elevated temperatures, sufficient hindered contraction which is greater than that normally allowed under "patternmaker's shrinkage."

Studies[15] conducted on the hot strength of moulding sands and cores show that certain mixes develop very high strengths at the elevated temperatures, as is shown in Fig. 17. Some sands develop strengths of over 1,000 lbs. per sq. in. in the neighbourhood of 2,000 deg. F. It is true they drop off to values of 5 to 100 or so lbs. per sq. in. at temperatures near 2,500 deg. F. But all these strengths are found in a sand under the actual conditions of casting, since there is a very pronounced temperature gradient that exists following the casting of the steel.[16] Thus, while the sand at the mould-metal interface is at a temperature of about 2,500 deg. F. and has a strength of perhaps 20 lbs. per sq. in., the sand at only $\frac{1}{8}$ in. away from the mould-metal interface would be at about 2,000 to 2,200 deg. and have a possible strength of 1,000 lbs. per sq. in. Sand of these high strengths will, of course, tend to prevent the normal contraction of the casting, with the result that hindered contraction stresses are formed.

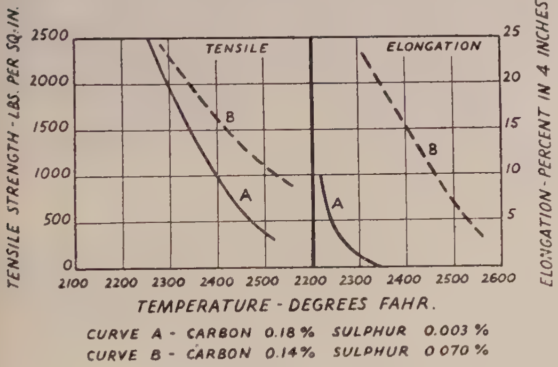


FIG. 18.—EFFECT OF SULPHUR ON THE STRENGTH AND DUCTILITY OF CAST STEELS AT HIGH TEMPERATURES. (HALL.)

From the work that has been done it has been established that for steel castings the maximum hot strength at 2,500 deg. F. for sands probably should not be over 25 lbs. per sq. in. If this figure is exceeded by very much the possibilities of hot tearing of the casting increase. Thus, sands and cores as well as casting design can be responsible for the formation of high hindered contraction stress at elevated temperatures.

The Susceptibility of Various Cast Steels to Hot Tear Formation

At any gathering of steel foundrymen where the subject of hot tears is discussed, sooner or later the discussion will turn to a debate as to which of the two types of cast steel, high carbon or low carbon, are less susceptible to hot tears. The discussion may also include acid *v.* basic steel melting practice as concerning susceptibility of hot tear formation. Opinion among foundrymen is about equally divided on these subjects.

The odd thing is that during these discussions the subject of stresses or stress formation is seldom considered. Perhaps it is taken for granted, though it is believed that the subject is of such importance that it can hardly be taken for granted. For without the presence of stress there will be no hot tears in well-fed sections, regardless of the composition of the steel or the manner in which it is made.

In the first place, the two steels cannot be directly compared. Two similar castings produced under similar conditions will not be under the same hindered contraction stresses at a common temperature. For example, it is assumed that one casting is produced from 0.15 per cent. carbon steel and that another similar casting is poured from 0.45 per cent. carbon steel. At 2,300 deg. F. under hindered contraction conditions a stress of 750 lbs. per sq. in. on the 0.15 per cent. carbon steel can be expected, whereas under the same conditions of hindered contraction the 0.45 per cent. carbon steel will have a stress of approximately only 500 lbs. acting upon it.[2]

Because of the higher stress acting upon the low-carbon steel, the natural reaction would be that the low-carbon steel is more susceptible to hot tears. However, this is not the entire story. It must be remembered that the low-carbon steel has a much greater strength and ductility at 2,300 deg. F. than the higher carbon steel. If values established by Hall[9] are used, as they can be considered comparative regardless of the section considered, the low-carbon steel is 1.4 times the tensile strength and eight times the ductility value of the high-carbon steel at 2,300 deg. F. Also, the hot tear formation temperature range is considerably smaller than that of the higher carbon steel. Thus, the two types of steels cannot be compared directly as to which is the best from susceptibility to hot tears.

In some cases the high-carbon steels will be less susceptible to hot tears, while in other cases the low-carbon steels will resist hot tear formation more effectively. Which steel to use to obtain the best results will depend on the mould conditions and the casting design. It must be remembered that hindered contraction can arise due to conditions of the mould, such as hard moulds and cores, or it may reach considerable proportions because of the casting design alone. It is suggested, however, that the low-carbon steels be first used if excessive hot tearing is encountered, since strength and ductility at high temperatures are necessary to combat stress concentrations at weak sections which are at higher temperatures than other sections.

If, however, the basic *v.* the acid practice is considered as to hot tear formation susceptibility, it is not believed that this can be treated quite so controversially. Inclusions, their content, type and characteristics, as present in a cast steel, have considerable influence on the mechanical properties of the steel at the very high temperatures. It is known that sulphur is quite an active inclusion former, and its presence under certain conditions can lead to the formation of quite harmful inclusion types.

Thus, it would seem that anything that could be done to keep the sulphur content as low as possible would be a step in the right direction regarding the susceptibility to hot tear formation. It has been shown that, as the sulphur content increases, the strength and ductility of cast steel at high temperatures falls off extensively[10] (Fig. 18). By the use of the basic practice, it is possible to keep the sulphur content to a low figure. Thus, it would seem that things other than sulphur content and inclusion count; being equal, basic steels are less susceptible to hot tear formation than acid steels.

Cast steels having a sulphur content greater than 0.03 per cent. will show upon deoxidation with a critical amount of aluminium (0.05 per cent.), an extensive chain-like eutectic pattern of inclusions.[12] Such a condition results in low ductility properties in castings. If the sulphur content is in the neighbourhood of 0.02 per cent., there is but little effect of low ductility upon deoxidation with small amounts of aluminium. Low ductility and low strength properties are obtained at high temperatures and are more pronounced than those recorded at atmospheric temperatures. Thus, from the standpoint of hot tear susceptibility, the sulphur content should be kept low, preferably below 0.025 per cent.

High contents of phosphorus (0.07 per cent.) lowers the strength and ductility of cast steels at high temperatures, but normal phosphorus contents below 0.05 per cent. do not have much effect on the high or atmospheric temperature properties of the steel.[9]

Inclusion Types

Certain inclusion types present in cast steel are conducive to the formation of hot tears.[3] Five types of inclusions have been recognised in cast steel in Table II. together with their sensitivity toward hot tear formation.[14]

TABLE II.—*Types of Inclusions and Sensitivity Toward Hot Tear Formation.*

Type.	Non-metallic inclusions.*	Hot tear sensitivity.
Silicate ..	Glassy silicates, round sulphides, and (intergranular sulphide films)	Prone to hot tear.
Eutectic	Round sulphides and intergranular sulphide films (alumina)	Prone to hot tear.
Galaxy ..	Alumina, round sulphides and films of oxide galaxies (inter-granular sulphides)	Less sensitive.
Alumina	Alumina, round sulphides, and (intergranular sulphide films or oxide galaxies)	Resistant to hot tears.
Peritectic	Alumina, duplex, round sulphides and (intergranular sulphide films)	Resistant to hot tears.

* Parentheses indicate appearance only in small amounts

The proneness to hot-tearing of cast steels of the silicate and eutectic types is explained by the fact that atmospheric oxidation produces eutectic inclusions at the surface of the casting, which seriously lowers the resistance of steel castings to hot-tearing. The intergranular sulphide form of the ternary eutectic is considered to be more prone to allow hot-tearing than the oxide galaxy form. The presence of the galaxy eutectic adjacent to the oxide phase makes the galaxy type of steel less sensitive to hot-tearing than the silicate or eutectic types.

The alumina and peritectic types are somewhat more resistant to hot-tearing at the oxidised surface owing to the formation of separated oxide particles rather than continuous intergranular films. Steels of the peritectic type (deoxidised with calcium) seem to have the same degree of resistance to hot-tearing that has been found in the strongly deoxidised steels that are not treated with calcium.

These remarks on inclusion types should be looked upon only as trends that may exist, for the other factors that are discussed in this Paper require greater consideration. The use of a certain type of deoxidiser is not going to make the steel relatively resistant to hot-tearing.

Influence of Pouring Temperature on Hot Tears

The temperature of the steel as it enters the mould is not directly a responsible factor for hot tear formation. Indirectly, however, temperature may be a factor. This may appear to be somewhat confusing. What is meant is that, if two steels are poured into similar moulds, one a high-temperature steel, the other a low-temperature steel, the high-temperature steel will not be more conducive to hot tears than the low-temperature steel. The reason for this is that hot tears do not form until the steel has solidified, and it is necessary for the hot steel to become cool steel before it solidifies. Therefore, there is no difference in the metal characteristics of the two steels as far as favouring hot-tearing.

Temperature can, however, bring about altering conditions in mould temperature gradients, and casting design may be such that temperature of the steel contributes to hot tear formation.

It is known that large uniform section castings should be poured on the cold side or as cold as the running of the mould will allow. In doing this the mould is not unduly heated at certain places to form hot spots in the casting. Points of change in sections are chilled to prevent hot spot formations and possible locations for hot tears. Castings of this design and type will probably develop hot tears if poured with high temperature steel.

This does not mean that all castings poured with high temperature steel are susceptible to hot tear formation. In fact, by the use of high temperature it is equally possible to prevent hot tear formation and at the same time prevent the formation of shrinkage cavities. If the casting is properly designed to allow for controlled directional solidification,[1] then every possible attempt should be made to establish large temperature gradients within the mould and casting. One of the best ways to do this is to use high temperature steel. Thus, the effect that temperature has on hot tearing depends entirely upon the casting design and mould construction.

Alloy Steels

In this discussion nothing has been said regarding alloy steels and how they react towards hot tear formation. Like carbon steels, the amount of strength and ductility that an alloy steel possesses at temperatures near the solidification temperature, and the rate at which it contracts under hindered contraction will in all probability determine its position as to its ability to resist hot tears. It is suggested that a comparison be made of a nickel-chromium cast steel of 0.35 per cent. carbon content with a plain carbon cast steel of the same carbon content. It is universally held that a nickel-chromium steel is quite susceptible to hot tear formation.

From information presented[9] it is possible to observe that nickel contents of from 2 to 5 per cent. do not increase the tensile strength or ductility of carbon steel at any particular high temperature. Chromium in percentages of around 1 per cent. appears to definitely lower the property values, while the combination of nickel-chromium reduces the values below those recorded for chromium. If a few values are singled out for both carbon and nickel-chromium steels of the same approximate carbon content, the values in Table III are obtained.

From these figures it can easily be seen that the nickel-chromium cast steels are much lower in strength and ductility than a corresponding plain carbon steel. Also the hot tear formation temperature range is longer.

There appears to be but little difference in the rate of hindered contraction of carbon and the nickel-chromium cast steels,[8] and hence the rate at which the stress is built-up is practically the same. Under a hindered contraction that may be normally expected in casting manufacture a stress of approximately 500 lbs. per sq. in. may be obtained at 2,300 deg. F. This is very close to the 840 lbs. per sq. in. at zero elongation as shown for the properties of the nickel-chromium steel as compared to the values of 2,000 lb. per sq. in. and 7 per cent. elongation for the carbon steel. Hence, it is easy to see that the nickel-chromium cast steels are very susceptible to hot tear formation.

It has been stated previously that solidification contraction may be responsible for the formation of hot tears. The information on the amount of solidification contraction in various steels is rather limited, and one is called on to make certain assumptions after reviewing all the assembled data on specific volume values. Thus, it appears that the total solidification contraction of a nickel-chromium steel would be perhaps greater than that of the carbon steel. If there has been no error in this deduction then poorly fed nickel-chromium steel would be more susceptible to hot tear formation (contraction cavities), due to insufficient feed metal, than the plain carbon cast steel.

TABLE III.—*A Comparison of Carbon and Nickel-Chromium Cast Steel Strength at High Temperatures.*

Deg. F.	Carbon cast steel.		Nickel-chromium cast steel.	
	Tensile strength, lbs. per sq. in.	Elongation in 4 in. per cent.	Tensile strength, lbs. per sq. in.	Elongation in 4 in. per cent.
2,500	400	0	60	0
2,400	1,300	0.5	380	0
2,300	2,000	7.0	840	0
2,200	3,200	33.0	1,900	15

Looking at the problem from these two viewpoints it is easy to see why the nickel-chromium combination is disliked in the foundry. It might be quite possible to continue at some length on the possibilities of various steels as regards their hot tear formation susceptibility, but a considerable amount of the information would be based on general trends instead of actual data. More important information could be obtained if steel foundrymen could carry out additional correlated testing. This would mean that some type of a test must be developed for hot tear susceptibility.

Hot Tear Prevention Measures

The best method of preventing hot tears is to keep hindered contraction stresses to low values. If hindered contraction values are greater than normal patternmaker's shrinkage ($\frac{3}{16}$ in. per ft.) hot tear formation is a distinct possibility.

Measures that should be undertaken to prevent hot tear formation are as follows:—

(1) Stresses that result from the hindered contraction of castings due to high strength moulds and cores should be kept at a low value. Do this by using relieving blocks or friable material in the backing sand, or by the use of low strength sand for the cores as tested at elevated temperatures.

(2) See that castings are so designed that they will not be closed, stress active systems wherein temperature gradients may be responsible for large stresses.

(3) Make ample allowances for solidification contraction so that every section may be well fed.

(4) Produce high quality steel of low inclusion content and of proper inclusion type.

(5) Apply proper chills to changes in sections to prevent hot spot formation.

(6) Use ribs, or cracking strips, at places to assist in preventing stress concentration.

(7) Keep the pouring temperature consistent with the steel casting design.

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Paper No. 775

The Continuous Production of Manganese Steel Castings from the Tropenas Converter

By L. W. BOLTON*, A.M.I.Mech.E. (Member) and J. HILL†, Assoc.M.C.T. (Associate Member)

Introduction

Austenitic manganese steel has a manganese content in the range of 11 to 14 per cent., with carbon 1.0 to 1.4 per cent. The silicon content is usually between 0.3 and 1 per cent., with phosphorus 0.1 per cent. maximum and sulphur 0.06 per cent. maximum. This steel, which is sometimes known as Hadfield's manganese steel after its inventor, Sir Robert Hadfield, was first commercially developed about 50 years ago, and its characteristics are now well known. In the as-cast condition it is relatively brittle, but after water quenching from a temperature of approximately 1,000 deg. C., it has remarkable toughness and wear-resisting properties. In this heat-treated condition the steel is practically non-magnetic and unmachinable. Its Brinell hardness is usually between 180 and 200 and its resistance to wear is due to its capacity to harden under cold work.

Although manganese steel can be rolled and forged, it is usually used in the form of castings. The melting point of the steel is given by Clark and Coutts[1] as approximately 1,345 deg. C., which is 170 deg. C.

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The authors were awarded Diplomas for this Paper.

lower than that of a 0.2 per cent. carbon steel. For the production of castings, it has excellent fluidity and in the case of light castings, gates and feeders can be similar to those used on high-duty grey-iron castings of the same size and weight.

For the production of light castings, two methods of manufacturing the steel are employed. The basic electric furnace, usually of the direct arc type, may be used, and the steel made by remelting steel scrap and ferro-manganese. With this method, an advantage is that an unlimited quantity of manganese steel return scrap, sprue and waster castings, etc., can be incorporated in the charge and remelted without serious loss of manganese. The alternative method is to produce a dead mild steel by means of the cupola and converter, usually of the Tropenas side-blown type, and add to this the requisite quantity of molten ferro-manganese which has been melted separately, either in a crucible or a small cupola.

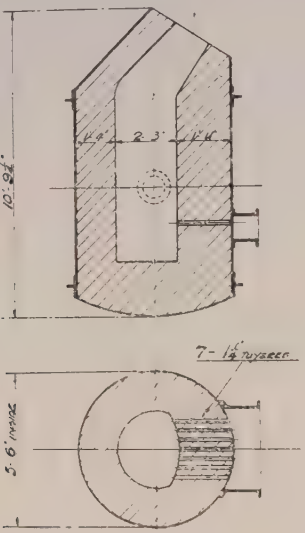

FIG. 1.—CONVERTER, 60 CWT. NOMINAL CAPACITY, LINED DOWN TO 25 CWT. CAPACITY.

With the latter method of manufacture, there is a limit to the amount of manganese steel return scrap which can be remelted, and the whole of the manganese content of scrap so used is lost. There is, however, a ready market for this scrap, and it is in demand as a manganese-bearing material for use in mixtures for the production of malleable and grey-iron castings, and also for remelting for the production of manganese steel by firms having electric furnace plant. Thus the inability of the cupola-converter plant to deal with large quantities of high-manganese scrap is not a serious economic handicap.

Quality of the Steel

The quality of manganese steel is normally determined by its microstructure and chemical analysis and because of the difficulty of preparing specimens, tensile tests are not used to the same extent as on carbon steels. Experience shows that in microstructure and composition, steel made by the converter process is at least equal to that produced in the electric furnace. Tensile tests on metal produced by the converter method taken on bars ground from clover-leaf specimens[2] have given an average maximum stress of 55 to 65 tons per square inch, with an elongation of 50 to 60 per cent. on 2 in. and 35 to 40 per cent. reduction of area. These figures compare favourably with those obtained on steel produced by other methods.

J. H. Hall,[3] an American authority on manganese steel, states, moreover, " the best informed opinion is that there is no difference in the quality of austenitic manganese steel produced by any of the commercial processes as measured by the strength, toughness, resistance to wear or any similar property." So far as the quality of castings made in this steel is concerned, in the as-cast condition, castings may be broken up without serious difficulty to enable examination to be made for internal porosity and to study the suitability of methods of gating and the effectiveness of feeders. The difficulty of machining the steel is not a hindrance in determining the soundness of castings.

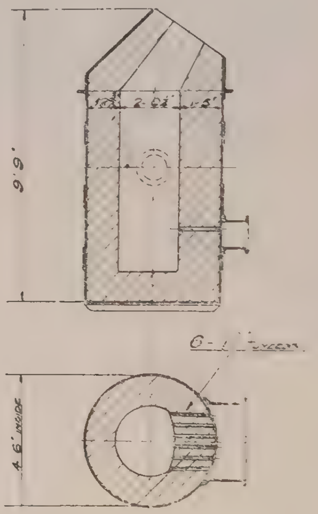

FIG. 2.—CONVERTER, 24 CWT. NOMINAL CAPACITY.

Operating Conditions

With both the electric and converter processes the finished steel becomes available in batches, and continuous metal can be obtained only by the use of a basic lined holding furnace, which must be heated either electrically or by other means. This is an expensive piece of plant, both to instal and operate. The problem dealt with in this Paper is the production of metal for light castings made on a continuous casting plant, by the cupola-converter process, without the use of a holding furnace. Batches of steel must be delivered to a pouring station as and when needed to suit the moulding production.

The method of producing the steel is briefly as follows: A weighed quantity of molten metal, sufficient for a heat, is taken from a cupola and transferred to a side-blown converter. While this metal is being converted, a weighed quantity of ferro-manganese is taken from a cupolette and transferred to the pouring ladle. The steel from the converter is teemed on to the ferro-manganese and the ladle is then taken to a pouring station in the foundry.

As the weight of a batch of steel varies, dependent on the condition of the converter lining, and as there also may be variations in the rate of moulding, the time interval between the production of batches of steel has to be capable of modification and at the same time the metal produced must be of satisfactory temperature. The steel must also be of correct composition and, because this depends on the mixing of a predetermined weight of ferro-manganese with a definite weight of steel, the blowing loss in the converter must be known with accuracy in advance.

When the plant was first put into operation, moulding production was low and batches of steel were required at relatively long intervals. With the method of operating the converter then used, blowing losses were erratic and there was difficulty in producing steel of suitable quality and temperature. A number of operating conditions were found to influence the results obtained from the converter, and an investigation into these was made to develop a technique which would satisfactorily meet the operating conditions set out above.

The Converter

Originally, the plant was provided with two converters of 3 tons nominal capacity, which were lined down to 25-cwt. capacity. The lining details of these vessels are shown in Fig. 1. Recently, one of these converters has been replaced by a vessel of 24-cwt. nominal capacity, as shown in Fig. 2. Two spare shells are available for the smaller converter and the remaining large converter is now used as a stand-by.

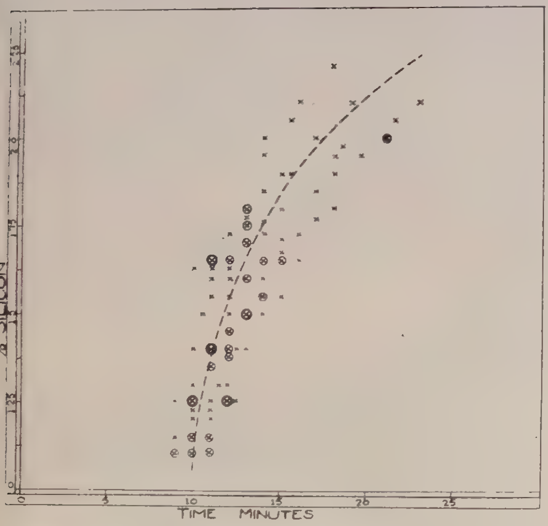

FIG. 3.—INFLUENCE OF SILICON ON DURATION OF CONVERTER BLOW.

The converter is normally supplied with air from a positive blower, capable of delivering 2,400 cub. ft. of air per minute against a pressure of 4½ lbs. per sq. in. A safety valve is provided in the blast system, which operates when a pressure of 4¼ lbs. per sq. in. is reached. A two-stage, high-pressure fan is available in case of a breakdown on the blower, capable of supplying 2,500 cub. ft. of air per minute and of working at a pressure of 4 lbs. per sq. in. These two units give identical results with regard to blowing time, temperature of steel produced and blowing losses.

The volume and pressure of air supplied to the converter is controlled by a manually operated valve in the blast system, which allows a proportion of the blast to escape to atmosphere. Owing to the situation of the blowing equipment and blast pipe, it has not been possible to instal volume-measuring equipment, and records are therefore only available of the blast pressures used. These pressures are registered in the blast pipe between the control valve and the tuyere box.

Effect of Metal Composition on Converter Blow

In this series of tests it was known that other factors, such as blast volume and pressure, metal temperature, blowing angle, and the condition and temperature of the converter lining, would influence the results obtained and these were therefore controlled as far as is possible in commercial practice, bearing in mind that production had to be maintained throughout the tests. Blast pressure was kept as near as possible to 4 lb. per sq. in., but it was sometimes necessary to reduce this slightly during the boil to prevent excessive ejection of metal. It was found impossible to avoid slight variations in other factors, but such variations enabled an assessment to be made of their value.

Silicon

A series of tests was made using cupola metal with various silicon contents over the range 1.0 to 2.2 per cent. The other elements were kept as constant as possible, the carbon content of the metal being approximately 3.0 per cent. and the manganese content 0.8 per cent. The time required to produce a heat of steel from the converter under these particular conditions, with metal of the various silicon contents used, is shown in Fig. 3. As would be expected, the time required increased with increased silicon content, but it was noticed that time tended to increase more rapidly after a silicon content of 1.5 per cent. was reached. The range of blowing times was also much increased with the higher silicon contents. This shows that converter conditions have a much greater influence on the length of the blow when the silicon content of the metal is high than when low silicon metal is used.

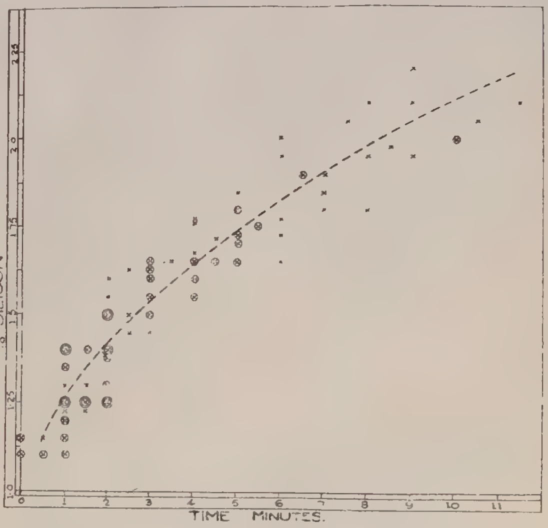

FIG. 4.—INFLUENCE OF SILICON ON THE TIME BEFORE THE APPEARANCE OF THE FLAME IN THE CONVERTER BLOW.

An interesting fact emerging from these tests was that the time elapsing before the appearance of the flame increased with the silicon content and after the appearance of the flame, blowing time varied very little over the range of compositions examined and was generally 8 to 10 mins. The relation between the silicon content of the metal and the time before the appearance of the flame is shown in Fig. 4. With silicon contents of the order of 1.0 to 1.2 per cent., the flame was almost instantaneously produced, whereas with silicons of 1.6 to 1.8 per cent., four to six minutes elapsed before the flame appeared. Fig. 5 shows the time taken between the appearance of the flame and the end of the heat. It will be seen that in the majority of cases this was between 8 and 10 mins., though occasionally a heat took slightly longer or less.

In order to examine the changes which take place in the metal before and after the flame is produced, samples were taken at intervals during the blow on three melts of differing silicon contents. The analyses of these samples are plotted in Figs. 6, 7 and 8. In Heat 1 (Fig. 6), the flame appeared after 1½ mins., when the silicon content of the metal had been reduced to approximately 1 per cent. In Heat 2 (Fig. 7), five minutes elapsed before the appearance of the flame, by which time the silicon had again fallen to approximately 1 per cent. from the 1.72 per cent. present in the original metal. This was confirmed by Heat 3 (Fig. 8) which originally contained 2.04 per cent. silicon and in which the flame was produced after a blowing time of 12 mins. These heats all took rather longer than would be required under normal conditions, due to the necessity for bringing down the vessel and shutting off the blast when taking the samples.

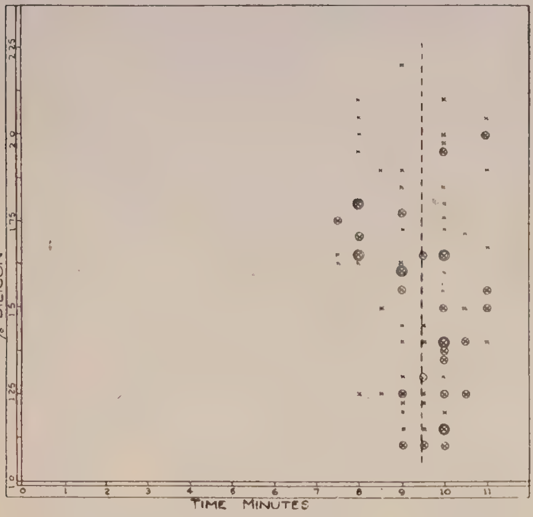

FIG. 5.—INFLUENCE OF SILICON ON DURATION OF CONVERTER BLOW AFTER THE APPEARANCE OF THE FLAME.

High-temperature cupola metal and a hot converter lining are most important factors in producing a flame rapidly with metal of low silicon content. With cool metal, or a cold vessel, the flame is not quickly produced and an unsatisfactory blow with high losses results. The temperature of the steel produced was related to the original silicon content of the metal. Above 1.8 per cent. silicon, however, towards the end of certain heats, the reaction was very violent and although a rapid blow was obtained, losses were heavy and the metal produced was cooler than was expected. Below 1.20 per cent. silicon, under the conditions of these tests, the metal was not sufficiently hot for the production of manganese steel of the required temperature. Because of the difficulty of obtaining with an optical pyrometer, accurate temperature readings on the molten metal as it was poured from the converter (due to fumes produced as the steel mixed with the ferro-manganese), temperature readings were taken on the converter bottom immediately after the metal was teemed. The average temperature produced from metal with an original silicon content of 1.20 per cent. was 1,540 deg. C., and that from metal with 1.8 per cent. silicon, 1,590 deg. C.

Manganese

In view of the desirability of utilising the maximum quantity of return scrap in the cupola charges, experiments were carried out to determine the influence of manganese on the converter blow. The silicon content of the metal was kept at approximately 1.5 per cent. and the carbon content at approximately 3.0 per cent. The manganese content was varied over the range 0.25 to 2.0 per cent. and a number of heats were made with each composition. Operating conditions were maintained as constant as possible and were similar to those in the previous tests.

It was found that manganese in the range examined had no influence on the length of the blow and all heats were completed in 10 to 14 mins., short and long heats being obtained with both high and low manganese. This element was also found to have little influence on the temperature of the metal produced. When present in quantities exceeding 1 per cent., however, there was an appreciable increase in the fluidity of the slag formed in the converter, and above 1.5 per cent. this slag was extremely thin and was ejected during the blow in relatively large quantities. Difficulty was experienced in holding back this slag when teeming the finished steel.

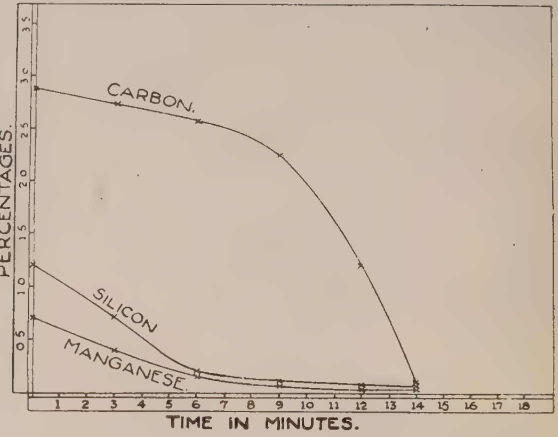

FIG. 6.—OXIDATION OF ELEMENTS IN CONVERTER BLOW. SILICON. 1.20 PER CENT.

Examination of the sulphur content of the cupola metal over a range of manganese contents showed that sulphur decreased as manganese increased. With manganese up to 0.5 per cent., the sulphur content of the metal was 0.09 to 0.10 per cent. With increasing manganese, the sulphur fell and was not higher than 0.07 per cent. with 1.5 per cent. manganese present. In producing manganese steel, the sulphur content of the steel is reduced to negligible proportions when the addition of molten ferro-manganese is made, so that in this particular process there is no special advantage from the use of cupola metal low in sulphur. This feature of high manganese content metal might, however, be of benefit in the production of low-sulphur carbon steel castings by the converter process.

In spite of the production of large quantities of fluid slag, no definite evidence was obtained that the use of metal high in manganese resulted in increased wear on the converter lining, but there appeared to be a slight increase in the lining erosion in the cupola when melting the higher manganese metal. For this reason, coupled with the increased difficulty of separating the converter metal from the slag, it was decided to limit the manganese content of the cupola metal to 0.8 to 1.0 per cent.

Carbon

To complete this series of tests, the influence of the carbon content of the metal on the converter blow was examined. A number of heats were made with silicon approximately 1.5 per cent. and manganese 0.8 per cent., with converter conditions as before. It was found that under the conditions operating, the original carbon content of the metal over the range 2.7 to 3.3 per cent. had no appreciable influence on the length of the blow. All heats were again completed in approximately 10 to 14 mins., but both short and relatively long heats were obtained with high and low carbon content. Although theoretically it would be expected that the amount of carbon to be removed would influence the duration of the blow, in practice other factors, such as the condition of the tuyeres and lining, temperature of the lining, etc., varied to an extent which masked the effect of the carbon content on both the length of the blow and on the temperature of the finished steel.

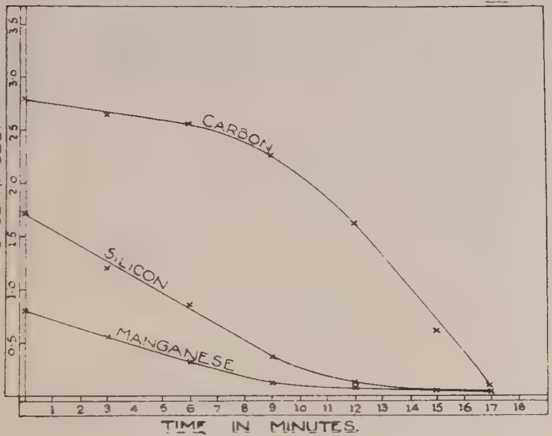

FIG. 7.—OXIDATION OF ELEMENTS IN CONVERTER BLOW. SILICON 1.72 PER CENT.

As a result of these investigations, it was possible to decide on the composition of the metal which would give the most consistent and trouble-free operation of the converter. For the smaller converter, which has a normal thickness of lining, metal of a silicon content of 1.2 to 1.4 per cent. is used, with a manganese of 0.8 to 1.0 per cent. The silicon content of the first heat of a shift is put up to 1.5 to 1.7 per cent. to offset the somewhat cooler lining on this heat. Later, the silicon content is kept as near the lower limit as possible. In the case of the larger converter, the silicon content is increased to this higher figure for the first five or six heats to offset the cooling action of the very heavy lining in this vessel. No attempt is made to control carbon content, and due to variations in the type of steel scrap melted in the cupola, this varies over the range 2.8 to 3.1 per cent.

OTHER FACTORS INFLUENCING THE CONVERTER BLOW

Temperature of Cupola Metal.—As already stated, the temperature at which the molten metal is supplied to the converter is very important in determining both the duration of the blow and the temperature of the resulting steel. The cupola is therefore operated to give a tapping temperature of not less than 1,430 deg. C.* and this is maintained throughout the shift.

Temperature of Converter Lining.—This is of equal importance, and as far as possible the temperature of the converter lining is not allowed to fall below 1,500 deg. C. before the next metal is charged. Blowing is then started immediately. Before the first heat of a shift, the lining is thoroughly and strongly heated by a coke fire using an air blast. Following this, operation is so continuous that the lining is not allowed time to cool. If a breakdown of long duration occurs in the shop, the converter lining is again preheated before work is resumed.

Blowing Angle.—The best results are obtained if the vessel is blown at an angle of 15 deg. from the vertical, and the weight of metal charged is arranged as near as possible to enable this angle to be used. An alteration of one or two degrees either way does not have any appreciable influence on blowing conditions, and the angle best suited to the quantity of metal charged is decided on from the appearance of the gases and sparks escaping from the converter mouth. Too much metal charged means that the angle from the vertical will be large and if carried to extremes, this results in a long blow and loss of metal from ejection. Insufficient metal charged necessitates a small blowing angle, and tends to give increased erosion of the lining opposite the tuyeres. With a charge of the correct size, it is sometimes necessary to bring the converter up from the 15 deg. position, nearer the vertical during the boil to minimise ejection.

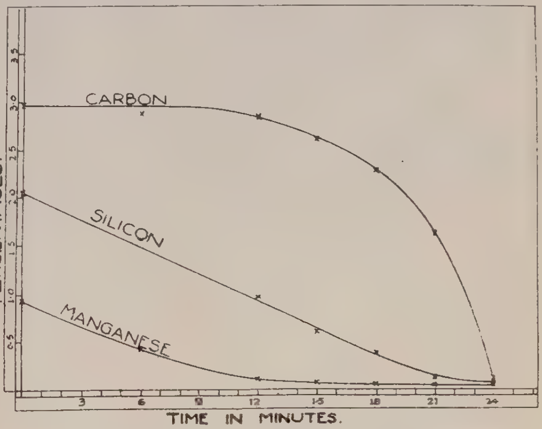

FIG. 8.—OXIDATION OF ELEMENTS IN CONVERTER BLOW. SILICON 2.04 PER CENT.

Condition of Lining and Tuyeres

The wear on the lining, by modifying the surface area of the bath, affects the time required to produce a heat; the larger the surface area, other conditions being constant, the more rapid the blow. With a badly worn lining, blowing losses are increased, principally through excessive ejection of metal. In itself, the increased holding capacity of the vessel and the consequent larger quantity of metal converted, does not appreciably increase the time required for a heat.

The nature of the erosion at the tuyeres has a very considerable influence on blowing conditions and maintenance of correct tuyere size and length is important.

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* This is an uncorrected temperature taken with a Foster disappearing filament type pyrometer on the metal stream.

Should the erosion at the tuyeres be seriously irregular, or if the tuyeres become less than approximately 6 in. in length, difficulty is experienced in controlling the blow, and there is apparently a tendency for the air volume to become excessive with normal pressures. Rapid heats can be obtained, but oxidation losses are high, and it is not easy to determine the true end point of the blow.

Patching of the walls and round the tuyeres is avoided as, in spite of every care in carrying out repairs, there is always a possibility of large pieces of patching coming away during a heat, which may result in bad converter conditions for the remainder of the shift. (For special reasons, repairs are made to the large converter, and this point will be dealt with later.)

Size of Mouth.—Maintenance of the correct size of mouth is of assistance in operating with constant blowing losses, as it enables the loss from ejection to be kept to a minimum. It is also of importance because of its influence on the appearance of the flame and thus on the interpretation of blowing conditions. A correctly sized mouth by restricting the escape of the gases has an effect on the conditions in the vessel during the blow. If excessively large, blast volume increases, and this causes an increase in oxidation losses. The mouth is therefore carefully fettled and patched to size after each shift.

Blast Pressure and Volume

As already stated, no information is available on the volume of air passing into the converter under various conditions of operation, and the blast is controlled by pressure readings. It is, of course, well known that for any particular set of conditions, air volume will vary as the square root of the pressure. Unfortunately, in practice, conditions which may influence air flow do not remain constant, but it is found that the appearance of the flame and the blast pressure reading can be used as a reliable guide to blast control.

With metal of 1.2 per cent. silicon and a blast pressure of 4 lbs. per sq. in., the time required to produce a heat is approximately 10 to 12 min. Usually, after the blow has been in progress for 5 to 6 min., it is necessary to reduce the blast pressure to 3½ lbs. per sq. in. to prevent excessive losses through ejection, but under these conditions the average time for a heat does not exceed 12 min. When using pressures of this order, blowing losses average 12 per cent. To increase the time of the blow when a longer blowing period can be allowed, a lower pressure is used, down to a minimum of 2.5 lbs. per sq. in. With this latter pressure and metal of the same silicon content, the average blowing time is increased to about 20 min., but the temperature of the finished steel is definitely higher than that of heats produced by the use of higher pressures. With low blast pressures, blowing losses are slightly lower and average about 10 per cent.

By the use of cupola metal of constant composition and with control of the factors described above, it is possible to produce steel of adequate temperature with converter losses which can be accurately forecast, and the metal can be supplied in batches at time intervals which can be varied to meet normal variations in mould production and in the weight of the heats of steel produced. Heats of manganese steel can be obtained at any required time interval between 20 and 30 min. When necessary, the plant has been operated over long periods to give three heats of steel per hour. It will, of course, be understood that certain factors, such as erosion of the lining and the tuyeres cannot be corrected during the shift, but by careful attention to the preparation of the lining and replacement as soon as this appears desirable, there is a minimum interference from lining conditions.

Converter Linings

The lining of the converter is rammed, using a proprietary acid refractory material, both for the bottom and for the walls. Before relining, the whole of the old lining material is removed. Attempts to reduce the quantity of new ramming required by leaving old material round the shell have been unsuccessful and this practice has been found to reduce the life of the new lining. The lining is built up round a wooden former using a pneumatic rammer and only a few inches of material is added at a time, the aim being to obtain a lining of uniform density. Special attention is given to the ramming of the tuyeres, which are made by passing tubes through from outside the tuyere box to locate into seatings in the wooden former. The tuyeres are carefully set at right angles to the vertical axis of the vessel. The new lining is air-dried for at least a week before use, and longer if circumstances permit. A coke fire is then lit inside and allowed to burn with natural draft for 15 to 20 hrs. The vessel is then used on the next shift.

On the small converter, the life obtained from a lining varies between 100 and 150 heats, with an average of 120 heats. The following table gives average figures taken over a period covering the life of seven linings:—

Number of days allowed for air-drying of lining	9
Number of heats from each lining	122
Number of heats per shift	24.5
Weight of metal charged into a lining..	152 tons 10 cwt.

On this converter, no patching is carried out apart from the repairs to the mouth of the vessel. During the above period, the amount of ganister used for this purpose averaged 7 lbs. per ton of metal charged. The amount of lining material used in lining the vessel is 6 tons, which gives a consumption of 88 lbs. of lining material per ton of metal charged. The total consumption of refractory in the small converter is therefore 95 lbs. per ton of metal charged.

In the case of the large converter, conditions are rather different, as, owing to the large quantity of material required to reline the vessel and the difficulty of relining, which has to be carried out *in situ*, the lining is patched with ganister after every shift to prolong its life as far as possible. In this way, a lining life of 230 to 270 heats is obtained, the average life being 250 heats, during which the metal charged amounts to 350 tons. The consumption of patching material averages 38 lbs. per ton of metal charged. Material used in lining the vessel amounts to 9 tons, so that lining consumption is 57 lbs. per ton of metal charged. This gives a total consumption of refractories of 95 lbs., which is exactly the same, per ton of metal charged, as the consumption of refractories in the small converter.

The price of the proprietary lining material is considerably higher than that of the ganister, and because of this the actual cost per ton of refractory used in the small vessel is one-third greater than in the large converter. When the additional time required to apply the patching to the large converter is taken into consideration, operating costs slightly favour the small vessel. Quite apart from this question of cost, experience shows that to operate without internal patching is much to be preferred, as this obviates the danger of patches breaking away during the operation of the vessel and thus causing an alteration in converter conditions.

On the recommendation of Mr. P. C. Fassotte, the practice of making an addition of sand to the converter immediately after the vessel is drained, has been adopted and has resulted in a marked improvement in lining life. After the slag has been drained away, the vessel is brought up to the horizontal position and 25 to 30 lbs. of silica sand is thrown in. This is distributed over the wall, especially in the area where the maximum wear occurs. Part of this sand frits on to the lining and thus replaces material eroded in the previous heat, and some of the remainder combines with free iron oxide and thus helps to prevent lining attack. The actual addition is controlled so that there is no build-up on the lining. The figures given above were recorded after the adoption of this practice, which has resulted in lining life being increased by an average of twenty heats.

Cupola Practice

The main requirements in operating the cupola are that metal of constant composition shall be produced at a rate to suit the demand, and that the tapping temperature shall be maintained at not less than 1,430 deg. C. Under normal conditions, the demand varies between 3.0 and 3.75 tons per hr., though it must be possible to maintain both temperature and composition when the demand falls below 3 tons per hr.

There is nothing unusual in these requirements and operation is quite normal. The charges used are of 6 cwts., and contain 75 to 80 per cent. steel scrap, which includes 8 to 10 per cent. manganese steel, the remainder being hematite. The silicon content of the metal is adjusted by an addition of ferro-silicon to the charges. It is found desirable to limit the steel scrap to a maximum of 80 per cent., because the quality and size of the steel available is variable. The use of 20 to 25 per cent. pig-iron enables a higher maximum hourly output to be obtained from the cupola when required than is possible with an all-steel charge, and also helps to reduce lining erosion.

The furnaces are of conventional design, with one row of tuyeres, and are lined parallel to a diameter of 30 in. from the tuyeres to the charging hole. The tuyeres are set at a height of 3 ft. 9 in. above the baseplate, and the lining is expanded to 36 in. dia. below the tuyeres. This enables a converter heat to be drawn at one tap, as the holding capacity of the well is approximately 35 cwts. This large capacity, together with the relatively light charges employed, allows complete mixing of the components of the charges, and no difficulty is experienced in holding the metal between the desired limits of composition. As the nominal capacity of the converter is approximately 24 cwts., four cupola charges are required for a heat with a new lining. The capacity of the converter increases as the lining wears, and the actual amount of metal required varies between four and five charges. Tapping slightly more or less metal than is produced from a definite number of charges has not been found to have any appreciable effect on composition, and this is no doubt due to the large quantity of metal which can be held in the well of the furnace. Checks are made on the silicon content of the metal at intervals of two hours, or more frequently if conditions necessitate it. Experiments have been made with the use of chill test samples in the form of wedges and flat plates, with the idea of using the depth of chill as a guide to the silicon content. It has been found, however, that variations in carbon content due to changes in the type of steel scrap used are sufficient to influence the depth of chill and mask small but important differences in silicon content.

In spite of the precautions taken to preheat the converter lining before the first heat of a shift, this is never quite so hot as it becomes after the third or fourth heat, and it is therefore extremely important that the first tap of metal from the cupola shall be as hot as possible. With the very deep well with which the cupolas are provided, special precautions have to be taken to ensure this. In preparing the bed, the fettling hole cover is left off as long as possible to allow the coke below the tuyeres to become highly incandescent with natural draft. When the hole has been closed, coke is added in small charges until a depth of 1 ft. 6 in. to 2 ft. is built above the tuyeres and is strongly heated. The tuyeres are then poked to consolidate the coke, and the bed is finished off to its final height of 3 ft. 6 in. above the tuyeres. The height is checked by means of a measuring rod, and the cupola is then charged and the blast put on as soon as possible after the cupola is full.

While the cold coke which is used to complete the bed is burning through and reaching a melting temperature, the superheating zone immediately above the tuyeres has time to attain its maximum temperature, and this results in the first metal becoming highly superheated when it passes through this zone. If the bed is burnt right through before charging begins, the first tap taken from the cupola is always cooler than when the practice described above is adopted. In the latter case, there is also a danger that light scrap and pig may begin to melt while the cupola is being charged, and this may result in a hard tap hole. A cupola melting a mixture of 80 per cent. steel, with tuyeres placed 3 ft. 9 in. above the baseplate, is especially prone to a hard first tap, and highly superheated coke in the well below the tuyeres, together with the method of making the bed described above, does much to overcome such difficulties.

A metal-to-charge coke ratio of 8:1 is normally found adequate to maintain the required temperature throughout the melt, but should the temperature fall, due to the use of unsatisfactory scrap or a reduced demand for metal, sufficient additional coke is used on the charges to maintain the temperature. With a minimum demand for metal, the maximum coke charge used to maintain the temperature is approximately 100 lbs. The output from the furnace is controlled by adjustment of the air supply.

Cupolette Practice

During a shift, a total of about 6 tons of molten ferro-manganese is required at a rate of 12 to 15 cwts. per hr. This is melted in a standard cupolette of 2 ft. 9 in. shell diameter, lined to 23-in. internal bore. The maximum holding capacity of the well is 6 cwts., and this is the maximum tap required for the largest heat of steel made in the converter.

The charges consist of approximately 112 lbs. of ferro-manganese and 14 lbs. of coke, no flux being used. Molten ferro-manganese has a very short life and care has to be taken to see that the bed is hot below the tuyeres, to avoid a hard first tap. Bridging and hanging of the charges must be prevented, as this results in cool metal and excessive lining wear, with variable losses of manganese. All the ferro-manganese and coke charged is therefore broken into pieces of approximately 4 in. cube. The shortness of the stack, which is only 4 ft. 6 in. above the tuyeres, is also a safeguard against hanging, and although some loss of heat occurs, due to the curtailed preheating space, the advantages gained outweigh this loss in thermal efficiency.

The average analysis of the ferro-manganese charged is 78 to 80 per cent. manganese, 6.5 to 7 per cent. carbon, and the analysis after melting is 74 to

76 per cent. manganese, with a carbon content of 6.0 to 6.5 per cent. The average losses of carbon and manganese on melting are about 6.5 per cent. and the total melting loss 7 per cent. The slag produced, without the use of any flux, is clean and fluid and contains approximately 50 per cent. MnO with 25 per cent. SiO_2 and 20 per cent. Al_2O_3.

Mixing the Steel

The properties of manganese steel vary slightly over the range of 11 to 14 per cent. manganese, and the most satisfactory material has a manganese content between 12 and 13 per cent. This is the composition aimed at when calculating the amount of ferro-manganese needed. The ratio used is one of ferro-manganese to 4.7 of metal from the converter, or a ferro-manganese addition of 21 per cent. of the weight of the converter metal available.

The molten ferro-manganese is tapped from the cupolette five minutes before the converter blow is expected to finish. The amount taken depends on the amount of steel which will be available, which is accurately known from the weight of cupola metal charged. The weight of ferro-manganese taken is roughly checked during tapping, on a dial-type spring balance from which the ladle is suspended. The ladle is then transferred for a more accurate weighing to a weighbridge at the side of the cupolette. If the weight is correct, the metal is poured into the manganese-steel ladle, any crust or skull being raked out. The empty ladle is put back on the weighbridge as a check to obtain the actual weight of ferro-manganese transferred to the steel ladle. This is necessary, because occasionally a skull may not be removed from the bottom of the ladle, thus causing the estimate of the ferro-manganese in the steel ladle to be incorrect.

In most cases, no difficulty is experienced in tapping the correct amount of ferro-manganese. If too much is tapped, it is a simple matter to pour some off into a pig mould. Should the quantity tapped be insufficient, the ladle may be returned to the cupolette for more, or failing this, a small deficiency may be made up with solid ferro-manganese, especially if hot material is available from excess poured down on a previous heat. Up to 56 lbs. of red-hot ferro-manganese has been used in this way, but not more than 28 lbs. of cold material is used, because of its chilling action on the steel.

As soon as the converter blow is finished, the steel is deoxidised with aluminium and a silicon addition is made, using 75 per cent. ferro-silicon to bring the silicon content of the finished steel to the desired amount. The ladle containing the ferro-manganese is then taken to the converter and the steel is teemed into it. The slag is held back and prevented from entering the steel ladle by means of a refractory brick held in position across the converter mouth. Pouring the steel on to the molten ferro-manganese in this way is sufficient completely to mix the two metals and a homogeneous steel results. Before this method of mixing was finally adopted, numerous check analyses were made on samples taken at various points when batches of the steel made in this way were being poured and it was found that the maximum variation in manganese did not exceed ±0.5 per cent.

The weight of the steel poured into the manganese steel ladle is checked on a dial-type weigher suspended from the overhead crane which carries the ladle. As soon as the required quantity of steel is obtained, pouring is stopped and the converter should, at this point, be just drained of metal. If in unforeseen circumstances, some steel remains in the converter when the necessary quantity has been taken, it is necessary to bring up another ladle to enable this steel to be teemed and pigged. It is very desirable that this should be avoided, as it causes time to be lost and a hold-up in the moulding shop may result, but it is a very unusual occurrence which results from the inadvertent tapping of too little ferro-manganese. Too little steel in the converter results in a high manganese content in the finished steel and may cause it to be out of specification on analysis. For this reason, it is essential that blowing losses shall not be greater than the figure anticipated. As soon as the steel has been teemed, the vessel is inverted to remove the slag, sand is thrown in as already described, and the next heat is charged, blowing beginning immediately.

On an average heat, the temperature of the converter bottom after the steel has been teemed is 1,550 deg. C. An uncorrected temperature reading taken with an optical pyrometer on the metal stream while the first casting is being poured usually gives a figure of 1,510 deg. C. From an average heat, forty castings are poured in ten minutes and the temperature of the last metal from the ladle is recorded as 1,430 to 1,440 deg. C.

METALLURGICAL CONSIDERATIONS

Carbon and Manganese

In the as-cast manganese steel, part of the carbon present exists as free carbides which are arranged in a network formation. This is the reason for the relative brittleness of the unheat-treated steel. The higher the carbon content, and especially if the carbon is high in relation to the manganese, the more carbides will be deposited out of solution during cooling from the molten state. The purpose of the heat-treatment is to take these carbides into solution and they are then retained in the austenite by quenching. If a large quantity of carbides are present in the as-cast material, a long heat-treatment cycle at a high temperature is necessary to take them into solution. In a satisfactory manganese steel, the carbon content is not more than one-tenth of the manganese content. In making the steel by the converter process, a small amount of carbon, say, 0.08 per cent., is present in the converter metal, and it is important that this amount shall not be exceeded. When the converter metal is added to the ferro-manganese, in spite of the previous deoxidation with aluminium and the addition of ferro-silicon, there is a loss of manganese amounting to approximately 3 per cent. of that added, giving, on a normal heat, an actual manganese content 0.5 per cent. lower than that expected from a calculation based on the weights and compositions of the materials used. This loss is not accompanied by a corresponding loss in carbon. If all conditions are correct, however, the relation between the carbon and manganese in the ferro-manganese is such that the analysis of steels produced by this process will show a manganese: carbon ratio of between 10.5 and 11:1.

Should a large amount of converter slag, especially if this is highly oxidised, enter the ladle with the steel, a considerable manganese loss can occur without any appreciable loss of carbon, and this also throws the two elements out of balance. Special care must therefore be taken to prevent the converter slag from passing into the steel ladle.

The carbides in a steel of 1.4 per cent. carbon and 14 per cent. manganese take slightly longer to go into solution during heat-treatment than those in a steel of 1.2 per cent. carbon and 12 per cent. manganese, treated at the same temperature, and this is a reason, apart from the need to economise in manganese, why the upper limit of 14 per cent. is placed on this element. In steels in which the carbon is out of balance with the manganese, for example, 1.3 per cent. carbon with 12 per cent. manganese, a longer heat-treatment cycle is necessary to produce a satisfactory structure.

Silicon, Sulphur and Phosphorus

Silicon increases the fluidity of manganese steel and a silicon content of 0.8 to 1.0 per cent. is desirable. The ferro-manganese used contains approximately 1.0 per cent. silicon and an addition of ferro-silicon is made to the metal in the converter to supply the remainder. If manganese steel is held in an acid-lined ladle, silicon is picked up from the ladle lining. When the plant was first put into commission, ladles lined with ganister were used for the manganese-steel. It was discovered that, when pouring 27 cwts. of steel in a total time of 10 min., the silicon content increased from 0.3 per cent. in the first casting poured to 0.9 per cent. in the last casting. Ladles lined with a basic monolithic material are now used, and no increase in the silicon content of the steel occurs.

The sulphur content of manganese steel is always low, and even when the sulphur in the metal from the converter exceeds 0.1 per cent., the greater portion of this is removed from the metal by the manganese. The sulphur in the finished steel is always less than 0.06 per cent., and for this reason no desulphurising treatment of the cupola metal is necessary.

The ferro-manganese normally available for the manufacture of manganese steel contains 0.2 per cent. of phosphorus. Phosphorus is not, of course, removed in the converter and, in fact, this element increases slightly due to concentration. It is therefore essential that the phosphorus in the cupola metal should be kept as low as possible, preferably below 0.06 per cent.

Production Costs

It is felt that this Paper is incomplete without some reference to the costs of producing manganese steel by the process described. Under present conditions, however, it is extremely difficult to give representative cost figures. Instead, a schedule has been prepared showing the materials consumed in producing 10 tons of molten manganese steel, having a manganese content of 12.5 per cent., on the basis of the production described. The figures are as follows:—

	Tons	Cwt.	Qr.	Lb.
Carbon steel scrap, for cupola melting, P 0.050 per cent. max. ..	6	13	1	9
Hematite pig iron, for cupola melting, Si 2.0 per cent., P 0.05 per cent. max.	2	10	0	0
Manganese steel scrap, sprue, etc...	–	16	2	8
Ferro-manganese for cupolette, Mn 78 per cent., C 7 per cent., P 0.20 per cent. max., 21 per cent. addition to converter steel	1	17	2	11
Ferro-silicon (75 per cent. Si) for cupola melting and addition to steel	–	4	1	17
Aluminium, for deoxidising converter metal	–	–	–	15
Coke, 12½ per cent. on charges in cupola and cupolette, including allowance for bed coke.. ..	1	16	2	0
Limestone, cupola flux	–	6	1	0
Converter lining material, consumption 88 lb. per ton of metal charged	–	6	2	0
Ganister, cupola repairs 35 lb. per ton melted.				
Cupolette repairs 26 lb. per ton melted				
Converter mouth, 7 lb. per ton charged	–	3	2	0
Firebricks, 40—42 per cent. alumina quality: Cupola 44 lb. per ton melted; Cupolette 50 lb. per ton melted (including allowance for relining both furnaces) ..	–	5	0	0

In obtaining the above figures, a melting loss of 7 per cent. has been allowed in the cupola and cupolette, and a blowing loss of 12 per cent. in the converter. In addition to the materials listed, electric power is used to raise the materials to the furnaces and converter, to supply the blast, and to operate the converter. The labour required depends to some extent on the mechanical equipment available. Governed by the operating conditions, seven to ten men are required to charge, tap and repair the cupolas, either two or three men are needed to operate and repair the cupolettes, and a further four men are required to operate and reline the converters.

The initial capital outlay on a plant of this type is considerably less than in an electric furnace installation capable of a similar output. With the converter process, as already stated, it is not possible to remelt the whole of the scrap produced and a market for the excess must be found. The total scrap in this plant, including sprue and waster castings, amounts to approximately 25 per cent. of the metal poured, that is, in producing 10 tons of manganese steel, 2.5 tons of scrap will be produced. Of this, rather less than 1 ton can be re-used in the process.

Acknowledgments

The authors' thanks are due to the management of the plant for assistance in carrying out the work described and especially to Mr. P. Davenport for his ready co-operation and assistance, and also to Mr. C. H. Kain and Mr. J. J. Sheehan for helpful advice. Acknowledgment is also made to Mr. J. W. Gardom, who designed the plant and supervised the work, and to whose enthusiasm and pertinacity the development of the successful technique has been largely due.

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Paper No. 776

A Wartime Steel Foundry—Some Problems and Developments

By E. D. WELLS* (Member) and A. JOHNSON* (Associate Member)

Introduction

In presenting this Paper, the authors have drawn their subject matter from practical workshop experience over the last few years. During the war, particularly, they have had little opportunity for genuine research. The requirements of war production have meant that speed has become so much more important than before in the development of either a new material or a new method. Under more normal conditions time is available to confirm results at each stage of an experiment before progressing to the next, but during wartime it is very rarely that circumstances have permitted such a thorough but often lengthy procedure; thus in a foundry, tackle has often been specially prepared for a method which, though it may appear promising, is far from proved. It is in this atmosphere that the authors have worked since the outbreak of war, and, therefore, they feel that little apology is needed for the very general nature of the subject matter and for the lack of figures and definite data.

Very many admirable Papers are presented containing a wealth of facts obtained by skilled observers, but there is often something of a gap to bridge between the results as obtained under experimental conditions and those actually realised in the shops. It is felt, therefore, that some observations of a general nature on results obtained in the stress of wartime production may be of interest to many founders.

There is little doubt that the need for improving both the quality and quantity of output to meet wartime requirements has resulted in many practices being adopted that previously were considered impossible or at the least inadvisable. It is in one sense lamentable, but nevertheless quite true, that in more than one direction the effect of a war is to speed up development in several ways in all sciences and industries, and necessity has sometimes led to a better article being produced with poorer materials.

If in places the authors have departed from a statement of facts to comment on future development in the foundry industry, it is hoped that the fascination of such a subject will render its own apology.

Cupola Practice

The practice of melting a high percentage of steel scrap in the cupola became necessary early in the war, due to the shortage of hematite pig-iron and the (comparatively speaking) plentiful supply of scrap. At the authors' works, however, this practice had been the custom for many pre-war years for purely economic reasons resulting from their geographical position in the country. For many years 80 per cent. scrap and 20 per cent. pig-iron formed the standard cupola charge. The pig-iron contained 4 per cent. to 5 per cent. silicon, and the scrap generally was very good, a big proportion being tram rails cut into short lengths. This charge was melted in Poumay cupolas with a nominal "grey iron" output of 9 to 10 tons per hr. The rate of melting with this type of charge averaged over a long period 6½ to 7 tons per hr.

Long experience of the Poumay cupola has shown that whilst possessing some advantages in melting medium to large scrap, because of the pre-heating of the charge, when light scrap such as boiler plate parings is used in quantity, the oxidation becomes excessive and a troublesome, frothy slag is formed. The only way to control this is to try to induce less oxidising conditions by increasing the coke-metal ratio to somewhat uneconomic proportions in which melting coke may rise to over 20 per cent. of the metal melted and the rate of output be seriously reduced. From results obtained elsewhere there seems little doubt that for melting the smaller type of scrap in a high scrap charge a cupola with a single row of large tuyeres sited below the wind belt is a better type of furnace than the Poumay with its small main tuyeres and subsidiary tuyeres giving a pre-heating but sometimes heavily oxidising zone.

Reverting back to the cupola charge, early in the war a long trial was made with 90 per cent. steel scrap and 10 per cent. iron, the latter still being of the 4 per cent. to 5 per cent. silicon order. Very little difficulty was experienced during this period, but it must be said in all fairness that the quality of the scrap at that time was very high, both chemically and physically.

This type of charge gave about 0.7 per cent. silicon in the metal prior to blowing, and unless melting was rapid and the temperature kept high, some difficulty was experienced in desulphurising for which a fluid metal is most important. Accordingly it was felt that for a Poumay cupola this figure of 90 per cent. scrap represented the absolute maximum, and then only if the scrap itself is ideal.

This practice was discontinued when supplies of high silicon hematite became scarce and low silicon American pig-iron (1 to 1.3 per cent. silicon) was supplied. A reversion was then made to 80 per cent. scrap and 20 per cent. American pig-iron, but as the silicon in the resulting metal rarely reached 0.5 per cent., considerable difficulty was experienced in getting efficient desulphurisation. It therefore became necessary to add Fe-Si to the cupola, and in this connection it quickly became apparent that 45 per cent. grade Fe-Si was better for such a purpose than the 75 per cent. grade, for the reason that the larger bulk for a given silicon addition gave more uniform mixing in the metal. Furthermore, it became necessary to watch very carefully the size of lumps of Fe-Si added with each charge, since large lumps give very uneven silicon analyses due to concentration, whilst very small pieces were subject to heavy oxidation and even sometimes being thrown up the stack by the blast.

This practice was followed until a short time ago, when once again a quantity of 4 per cent. silicon hematite pig-iron became available, and it was then made possible to revert to the type of charge mentioned earlier, namely, 80 per cent. scrap and 20 per cent pig-iron, without any addition of Fe-Si to the cupola.

Experiments were made early in the war in melting 100 per cent. scrap in this type of cupola with and without Fe-Si additions, but in both cases a poor measure of desulphurisation was achieved, due to cold and/or sluggish metal. The resultant steel, moreover, even when omitting desulphurisation and tapping direct from cupola to convertor, was only fluid enough for heavy castings, and the needs of wartime production at the authors' foundry, involving a big proportion of light section castings, made this practice quite impossible, apart from the question of high sulphur content.

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Future of the Tropenas Process

Regarding the Tropenas process as a whole, the authors firmly believe that there are many developments still possible that will keep it well to the fore in steelmaking practices for many years to come. Its flexibility and its speed of production are still unrivalled by any other method of making steel, but there is still a somewhat variable set of characteristics obtained from successive Tropenas heats resulting from the varied state of oxidation reached at the end of each blow, and from the difficulties encountered in keeping phosphorus and sulphur low. The photoelectric system, spoken of occasionally as the "electric eye," about which the authors have heard little but hope a good deal, would appear to have great possibilities in removing some of the lack of uniformity in Tropenas steel-making caused by the reliance placed on the human element in judging the end of a "blow," and it is felt that full information on this subject would be welcomed by all the foundries employing the Tropenas process.

TABLE I.

	Old type lining.		Rammed dolomite lining.			
Blow						
1.. ..	0.049	0.052	0.038	0.036	0.037	0.032
2.. ..	0.049	0.047	0.036	0.037	0.034	0.037
3.. ..	0.037	0.039	0.034	0.032	0.038	0.036
4.. ..	0.038	0.042	0.033	0.034	0.042	0.039
5.. ..	0.037	0.044	0.032	0.036	0.041	0.038
6.. ..	0.046	0.051	0.043	0.034	0.040	0.040
7.. ..	0.040	0.050	0.032	0.036	0.040	0.036
8.. ..	0.053	0.048	0.034	0.032	0.037	0.037
9.. ..	0.054	0.047	0.035	0.040	0.038	0.036
10.. ..	0.040	0.046	0.038	0.038	0.032	0.038
11.. ..	0.047	0.044	0.030	0.032	0.036	0.038
12.. ..	0.045	0.050	0.032	0.034	0.037	0.037
13.. ..	0.051	0.051	0.036	0.038	0.032	0.035
14.. ..	0.054	0.046	0.040	0.037	0.030	0.034
15.. ..	0.054	0.042	0.041	0.032	0.032	0.038
16.. ..	0.048	0.046	0.033	0.036	0.038	0.036
17.. ..	0.051	0.047	0.036	0.038	0.041	0.032
18.. ..	0.045	0.043	0.037	0.041	0.036	0.038
19.. ..	0.048	0.044	0.034	0.040	0.036	—
20.. ..	0.048	—	0.036	—	—	—
Average ..	0.047	0.044	0.035	0.036	0.036	0.036
Highest ..	0.054	0.052	0.041	0.041	0.042	0.040
Lowest	0.037	0.039	0.030	0.032	0.030	0.032

One of the most difficult problems in the Tropenas process is the control of phosphorus. A good deal can be done by careful scrap sorting, but, nevertheless, it is very difficult even in normal times to achieve regular figures below 0.05 per cent. At the present time the best solution, and the one adopted by many founders, is to run the acid Tropenas in conjunction with the basic electric process; thus are the speed and flexibility of the former married to the supreme quality and analytical accuracy of the latter.

Shortly prior to the war, the late Mr. Deschamps made a great effort to adapt the Perrin process of dephosphorisation of finished steel to cupola melted metal. The fear was expressed that dephosphorisation could not be effected in the presence of approximately 3.5 per cent. carbon since it was considered almost certain that the carbon would combine with the oxygen generated from the slag and intended for the oxidation of the iron phosphide prior to its combining with the lime in the slag. A visit was made to France for the express purpose of obtaining M. Perrin's views on this matter, and he expressed the opinion that it might nevertheless be possible to effect some measure of dephosphorisation in the presence of a large percentage of carbon. Experiments were accordingly made, but lacking at first an electric furnace for the fusion of the required slag, a trial was made with the slag in the unfused state. The trial was a failure, no visible reaction of any magnitude taking place, and there was no reduction of phosphorus.

The next experiment was made at Braintree with the kind agreement and co-operation of Messrs. Lake & Elliot. The slag was melted in the electric furnace and the cupola metal tapped on to it from a considerable height, as in the Perrin process for treating finished steel. A violent reaction started immediately and both slag and metal boiled out of the ladle. The dephosphorisation achieved was negligible, and it was agreed that the reaction was so dangerous and beyond control that no useful purpose would be served by continuing experiments on these lines.

Another development of the near future likely to lengthen the life of the Tropenas process is an improvement in desulphurisation arising from the employment of basic linings for the buckets in which the operation is carried out. A section is now devoted to reporting the progress made so far in the authors' foundry.

Desulphurisation in Basic Lined Ladles

A start was made over a year ago to determine what improvements could be effected by lining the bucket used for desulphurisation with some form of basic material. Hitherto practically every user of soda ash for removing sulphur from cupola iron has had his own method of lining the ladle used for this purpose, a big proportion of these linings being of an acid nature to a varying degree. In view of the strong basicity of soda ash, it is rather surprising that it has taken so long to develop a good reliable basic lining for this process, but experiments made so far, although not yet completed, suggest quite definitely that, with all other conditions unaltered, a basic lining gives a very definite increase in desulphurisation.

After consultation with Mr. N. L. Evans, of the Imperial Chemical Industries, Limited, and Mr. E. Shaw, of the Refractory Brick Company of England, Limited, who have shown very great interest in all the experiments, it was decided to try using stabilised dolomite in different forms.

Stabilised dolomite, its composition and manufacture, is fully described in the Journal of the Iron and Steel Institute by Swinden and Chesters. So far the material has been used as a lining rammed round a former, in the shape of unfired bricks, and also as fired bricks. Experiments are now in hand using unstabilised dolomite bonded with tar, but the results could not be obtained in time for publication.

For the first experiment the material was used in the ground state with water added to about 6 per cent. and rammed round a former. The lining was dried slowly, first with wood, then with partly-burnt coke, and was finally heated over a ladle fire prior to being used. After one day's use, during which some 70 tons of cupola iron were treated, very little damage was done to the lining, and the increase of capacity of the bucket was negligible. The improvement in desulphurisation, moreover, was very good—not only was the average figure lower, but there was much greater regularity. Some typical figures are given in Table I.

This lining was used for four successive days without any repairs being necessary, but towards the end of the fourth day the bucket was rapidly "gaining weight," finally holding nearly 4 tons instead of 3 tons as new. An attempt was accordingly made to patch the bucket, but the only material available was the same as that used for ramming and was decidedly "short" for the purpose. After patching and careful drying the ladle was again put into use, and after very few heats it became quite clear that the patching would soon all come away from the original lining. Further attempts to patch were made, but no matter how the procedure was changed, the results were always as bad. A repeat trial was made with a newly rammed lining and a similar set of results was obtained. The results at this stage were summarised roughly:—(1) Better average desulphurisation; (2) greater regularity; and (3) poor life, rendering the use of this material uneconomical.

In connection with (3), it must be pointed out that at this stage it is rather hard to state what is good economy in this respect and what is not. For instance, it is considered likely that most founders would be prepared for a rise in cost of liquid steel of a few shillings per ton if they could achieve a greater reduction of sulphur, since improvement in the quality of the steel and a greater freedom from hot tears is most likely to result, with corresponding economy at a later stage of manufacture.

Lining of Unfired and Fired Bricks

For the next experiment it was decided to try a lining of unfired bricks. As these bricks are moulded under great pressure and require very special moulds, it was not possible at the time to obtain the shapes desired. The bricks supplied were side arches and, being unfired, were of a crumbly nature. In spite of all precautions, therefore, it was not surprising that there were some bad joints in this lining, which, together with the fact that there were three to four times as many joints as would have been necessary if proper ladle tiles could have been used, gave the lining a short life. After only one day's use the lining was obviously failing badly, and although attempts were made again to patch the lining, the repaired portion would not adhere to the parent lining, and after only four days' use the whole lining was finished. The measure of desulphurisation reached, however, was remarkably good, giving very similar results to those obtained with the rammed lining.

For the third experiment we used bricks of a similar shape, but in the fired state. Very much better joints were obtained and, after careful drying, the ladle was put into use. Results obtained on 10 different occasions are given in Table II.

TABLE II

Blow										
1 ..	0.037	0.035	0.030	0.032	0.040	0.043	0.045	0.042	0.040	0.040
2 ..	0.035	0.034	0.032	0.037	0.037	0.040	0.047	0.043	0.037	0.042
3 ..	0.032	0.039	0.035	0.032	0.028	0.043	0.040	0.040	0.040	0.045
4 ..	0.033	0.036	0.030	0.037	0.026	0.044	0.039	0.044	0.039	0.045
5 ..	0.032	0.038	0.034	0.035	0.033	0.044	0.037	0.043	0.039	0.045
6 ..	0.043	0.035	0.034	0.030	0.029	0.042	0.042	0.040	0.036	0.036
7 ..	0.032	0.035	0.043	0.030	0.032	0.045	0.040	0.039	0.045	0.037
8 ..	0.032	0.030	0.031	0.038	0.035	0.045	0.039	0.041	0.039	0.036
9 ..	0.034	0.032	0.030	0.028	0.026	0.043	0.040	0.048	0.040	0.043
10 ..	0.035	0.030	0.032	0.026	0.038	0.040	0.042	—	0.038	0.040
11 ..	0.034	0.035	0.035	0.033	0.035	0.039	0.044	—	0.040	0.034
12 ..	0.034	0.035	0.033	0.030	0.032	0.045	0.043	—	0.040	0.037
13 ..	0.033	0.034	0.034	0.029	0.031	0.045	0.044	—	0.035	0.040
14 ..	0.039	0.034	0.037	0.030	0.030	0.052	0.045	—	0.040	0.039
15 ..	0.035	0.037	0.032	0.032	0.031	0.048	0.046	—	0.044	0.044
16 ..	0.030	0.036	0.030	0.031	0.030	0.045	0.039	—	0.045	—
17 ..	0.035	0.038	0.031	—	—	0.043	0.038	—	0.046	—
18 ..	0.037	0.033	0.030	—	—	0.043	—	—	0.047	—
19 ..	0.035	0.038	0.040	—	—	—	—	—	—	—
Average ..	0.035	0.035	0.033	0.032	0.032	0.044	0.042	0.042	0.041	0.040
Highest ..	0.043	0.039	0.043	0.038	0.040	0.052	0.047	0.048	0.047	0.045
Lowest ..	0.030	0.030	0.030	0.028	0.026	0.039	0.037	0.039	0.035	0.034

After these early troubles in patching had been reported to the suppliers, a new patching material was submitted. After the fifth day in the life of this particular lining, this material was used, and proved to be very much more workable than that previously supplied and stood up very well to a full day's use. Study of the figures above shows very distinctly that the results from the sixth day onwards were much poorer than those obtained when working on the original lining, so that, although a better material for patching has been produced, a falling off in the standard of desulphurisation is observed. At the present time no explanation can be found for this, so that the matter is still in a slightly unsatisfactory state.

As will be seen from comparing the latter figures in Table II with those obtained from the old type of slightly acid lining (see Table I), the results achieved by the patched dolomite lining are little better than those obtained from the old type of lining. It is regretted that no more up-to-date information can be offered on this matter, but the authors are confident that a little more time devoted to this problem will result in the attainment of a really satisfactory use of basic-lined ladles for desulphurising. It is quite possible that the experiments now being made with tar-bonded dolomite may prove to be a most satisfactory method, since it has been used in some works for several years for the transfer of metal from mixers to Bessemer converters, during which it is believed that the life of the lining is good and that a considerable measure of desulphurisation is carried out.

Whirl Gate Head

One of the greatest developments in steel castings in recent years is undoubtedly the introduction of the "whirl gate" head principle, which has been used for some years for certain non-ferrous work but has only recently been developed for steel castings. It is a great pleasure to take this opportunity of acknowledging the debt owed to Mr. R. L. Brown, Mr. Davenport and Mr. Speakes, of Messrs. Hopkinsons, Limited, for the pioneer work they have done in this respect and the freedom they have shown in disclosing the process to the industry.

A few of the more obvious advantages which are gained from this method are enumerated as follows:

(1) A great saving is made in the cost of oxy-acetylene burning and grinding, due to the better positioning of the heads and the small ingates which can be used.

(2) An increase in yield of casting from liquid steel can often be obtained by feeding 2, 3 or 4 small castings from one centrally placed whirl gate head. A head so placed forms a first-class reservoir of hot liquid steel, the very opposite to what was achieved by the older method of using many small heads, few of which fulfilled any useful purpose.

(3) By taking advantage of the temperature gradients of the steel, smaller heads may sometimes be used than is possible under the old system where a great mass of riser may be needed to counteract the fact that the hottest steel is near the runner—possibly at the bottom of the casting—and the coldest steel is in the head.

(4) Cleaner castings are produced through the whirling motion of the steel in the head keeping any sand washed in by the runner in the centre of the head and out of the casting.

It has been said that a greater height of head may often be necessary when the riser is on the side of the casting. This is following the belief that a certain height of steel is needed above the top of the casting to give the necessary pressure to feed the job. This height, which is taken as equal to the height of ordinary gravity heads—plus the depth of head down the side of the casting—would admittedly be excessive. However, the recent Paper given by Messrs. Taylor and Rominski on the use of atmospheric pressure in the making of steel castings successfully explodes this theory. As long as the top of a whirl gate head is kept open to the atmosphere, the height of the head need only be calculated in relation to the amount of feeding to be done, irrespective of its height above the top of the casting.

Use of Whirl Gate

In the authors' foundry, the whirl gate is used to advantage on a large number of jobs, a few examples which may prove of interest to steel founders are illustrated on the next page.

Figs. 1 and 2 show a simple crankshaft and one slightly more complicated. The thickening up pieces shown in the sketch were added to avoid any restrictions of feeding to the heavier sections beyond. These castings, although made in sand mainly composed of silica sand, reclaimed sand and Fulbond, obviously must be sand-free. This has been largely achieved by the cleansing action of the whirl gate head, and a large number of both types of castings has been produced sound and without blemish.

Fig. 3 is a good example of the better positioning of heads which is possible under the new method. This casting would usually be made with a head on the boss and one on the flange, with a resultant cavity at "A" unless the second head were heeled over the side. With one head feeding two castings—positioned as shown in the sketch—these brackets are being more perfectly sound. The bracket shown in Fig. 4 would have been difficult to make sound by any other method. If the pattern had been altered and cast with the boss A at the top, with the runner placed at the bottom for easy running, boss B would have had the hottest metal and shown a cavity. With the old type of heel head on the side, the ingate would assuredly have been made bigger than the boss with a subsequent excessive amount of cutting off.

Fig. 5 shows four bevel pinions cast off one large head. A saving in steel and ease in pouring are claimed in this case. The burning off of the head is less than is usually needed, but it is believed that this can be saved still further. Experiments are in hand casting the pinions the other way up and the ingate merely on the surface A. The height of head will only be the same despite the fact that the ingate is much lower than the top of the casting.

Sand

It has always been a difficult proposition in most foundries to dispose of used sand. This is now more of a problem than ever before. Labour for the removal of sand is almost impossible to procure and a fleet of lorries is very difficult to maintain. On the other hand, supplies of new sand have become erratic and unreliable for the usual large quantities. Therefore it has been borne upon many foundries to utilise more of the used sand. This has certainly been the trend for a number of years, but the war has given an added impetus to this development. Different types of sand reclamation plants are in use all over the country, but there is still much to be done in this respect. Without adequate means of removing the silt, a moulding sand based on a high percentage of used sand tends to become very friable, and when dried at only medium temperatures for any length of time, cracks and spalls rather badly. To get good consistent results from old sand, it is better merely to reclaim the grains of silica sand and remove the fines and burnt clay. Any fusible elements and fines which are needed in the milled sand can be re-introduced by the addition of a percentage of good naturally-bonded moulding sand.

Ordinary reclaimed sand from a jobbing foundry where different grades of sand have to be used is bound to be erratic in its qualities. Strict supervision is necessary on the moulding sand as produced from the mills. Any substantial increase in green strength which is usually accompanied by a lower permeability must be counteracted at once—usually by an addition of free silica sand.

Supplies of bentonite have been short, necessitating much investigation into the different types of clays available as a substitute. Several have been tried, but most are far inferior in green strength, and the sand tends to crack when used for deep mould faces. The best substitute so far used in the authors' foundry is Fulbond in its various grades, generally fully supporting the findings of the moulding materials sub-committee of the Iron and Steel Institute. Fulbond is still, however, much inferior to bentonite in bond and resistance to erosion. A larger quantity has to be used to obtain the same green strength. This means a lower permeability at once, and through time, greatly affects the reclaimed sand. This becomes far less permeable without possessing a greater green strength and, consequently, a much less percentage of reclaimed sand can be used—the opposite effect to that which is sought.

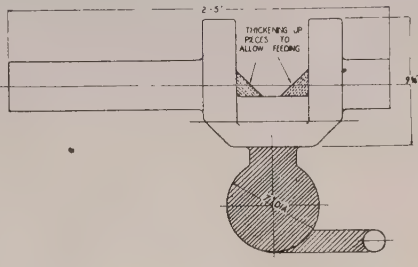


FIG. 1.

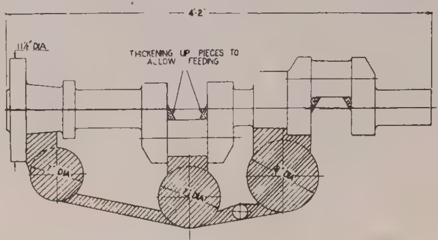


FIG 2

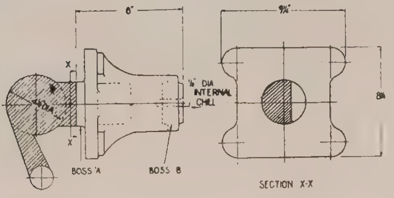


FIG. 4

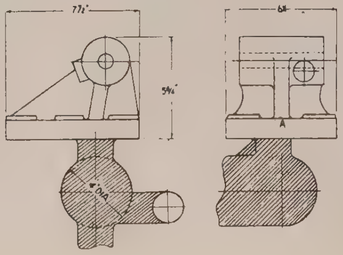


FIG 3

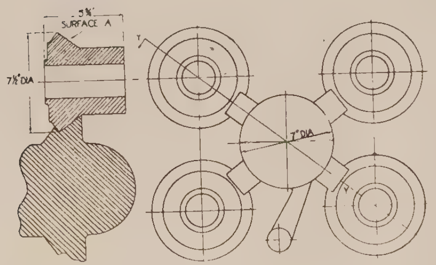


FIG 5

The Fulbond mixtures do not stand up to the metal as well as those made from the stronger clay. In fairly heavy sections there is a tendency for the sand to burn on to the casting, and even with medium work if the runner of necessity has a scoring effect the sand fails completely to stand up to the test. In some cases, when scabbing or erosion has occurred, it has been found necessary either to go back to the use of bentonite—which has completely cured the faults—or to take special precautions with nailing, etc.

An interesting development in recent years has been to discard clays entirely and use more organic substances such as the various proprietary core compounds. This has been sufficient to cure scabbing and erosion on some really bad cases, even when using it for shop-dried green-sand cores. After casting, of course, the sand is much easier to knock out when using these core compounds, and this alone has been sufficient to bring about a great saving in labour, apart from the benefits derived from the better castings.

Dust Problems

Although many problems existed before the war arising from the presence in the foundry of a dusty atmosphere and from the necessity for grinding surfaces of castings on which sand was present, it is only true to say that most, if not all, of the manifestations of this trouble have become of a more serious nature during the war. The reasons for this are many, the chief ones being:—(*a*) Poorer ventilation due to the "blacking-out" of shops; (*b*) more operatives in a given area; (*c*) longer hours of work; and (*d*) in some cases enforced change of foundry materials has tended towards a rougher casting requiring more grinding.

The authors feel that theirs is not the only foundry where the dust problem has been attracting some attention of recent years, and that practically every foundry in the country is now giving serious thought to the solution of this problem. No attempt is being made by the authors to define what is meant by silicosis, either its precise cause or its development and physical effects, since they wish at all costs to avoid provocative statements on a subject which is primarily one for medical research.

The author's concern is simply that the

presence in the atmosphere of any dust of a siliceous nature is a potential source of danger to workpeople, the effects leading to anything from mild laryngitis to the last stage of silicosis. Remove the root cause of this dusty atmosphere and it will be possible to deal with the whole range of forms of such illness at once, and it is towards the complete solution of this problem that founders must concentrate. In recent years the Home Office have taken a very much greater interest in this dust problem, and it is most likely that before long there will be new legislation governing working conditions in the foundries. This apart, the medical profession, in the form of local general practitioners, is taking a close interest in the matter, and it is most necessary that these good folk have confidence in one's working conditions, the alternative being high absenteeism covered by medical certificates.

Methods of Dealing with Dust

The five most common methods to-day of dealing with the dust menace are:—(1) Provision at specific points where dust is caused of hoods connected by pipes to cyclones, the dust being collected in bag filters or similar arrangements; (2) the wearing of respirators by the workpeople; (3) the employment of a company's doctor to ensure that men with a medical history embracing lung or throat troubles are not started on a dust-risk job and to make periodical examinations of men who are engaged on such operations to make sure that their health is not being impaired; (4) elementary devices such as watering the floor, etc.; and (5) forms of roof ventilation either by fans, or by means of a purely static system.

The first four of the above methods are each in its own way admirable, and a thorough combination of all goes a long way towards the complete solution desired. They are all to be seen in various foundries to a greater or lesser degree, and there is little doubt that an intensification of such methods will lead to further improvements.

The fifth method mentioned is, in the authors' opinion, not a highly effective one when viewed from the point of dust extraction. Such arrangements can be very satisfactory for removing hot air, fumes, smoke, etc., but do not achieve a really first-class result with actual dust, since, by the time it has been drawn to the roof, everybody has had an opportunity of inhaling dust particles.

A few comments on the other points tabulated are perhaps not out of place. With regard to dust extraction devices of the cyclone type, these are of many sorts and sizes, and are, generally speaking, effective. In many cases there is a tendency for the designers to under-estimate what is required of them, with the result that they deal with, say, 80 per cent. of the dust at a given place and allow the remainder to escape. This type of plant is also somewhat troublesome when it comes to disposal of the dust collected in the bags, and it is likely in this connection "sludge" methods of collection and disposal will one day supersede the bucket method. Referring to the question of respirators, there are nowadays to be had very effective designs, and improvements in comfort to the wearer have resulted in recent years. Nevertheless, difficulty is sometimes met in persuading men to wear such devices, a claim being made that they make breathing difficult when great muscular effort is called for.

It is a practice in some foundries, and is to be highly recommended, to issue each man with a freshly cleaned and disinfected respirator before each shift. The respirators are kept in a room devoted solely to the purpose, and a man is employed to carry out the cleaning, storing in bags and re-issue at the start of each new shift. Such an arrangement has been found in practice to be a real encouragement to men to wear these respirators. A similar idea has been adopted for shot-blast operators, each man having two helmets which are scrubbed and disinfected on alternate shifts.

Referring to the works' medical officer, his position is a very difficult one. He is in the company's employment and may, because of that, become the object of some suspicion by workpeople and local doctors alike. He will also occasionally run counter to the views and wishes of the production staff, who may regard his proposals as a brake on production. He must be what may be termed an "industrial psychologist," and he must understand workshop practices and customs, together with all the forms of malingering and grousing to which human nature is sometimes a prey. He is, however, a very necessary institution and any differences of opinion between production folk and the medical adviser must remain in the realms of healthy controversy, with a real understanding on each side for the other's difficulties.

Some Likely Future Developments

Arising now from this last section and from the short section on sand practice, the authors wish to comment briefly on two developments which, in their opinion, are likely to go hand in hand. These are:—(1) The increased adoption of synthetic sand practice, with particular reference to the use of the single sand process; (2) the hydro-blasting of castings.

These two subjects are allied for the following reasons:—First, the hydro-blast, in addition to cleaning castings, also reclaims and reconditions a big proportion of sand, and, secondly, both practices tend to lead to the elimination of dust at some of its main sources and, therefore, in many cases become of more importance than the five methods of elimination of dust dealt with in the previous section.

By the single sand process the authors mean a system in which "backing sand" is eliminated, one sand only being used for the mould part. This, in a sense, sounds an extravagant use of sand, but so is the practice still common to-day, with the use of separate facing and backing sands, of disposing to dumps of hundreds of tons of used sand every week. The space taken up by this sand, the danger to health caused by its presence (in the dry state) in the shop, the cost of its removal and replacement by hundreds of tons of new sand brought from a distance, is no light matter.

Sand plant design has improved greatly in recent years as experience has been gained on the reclamation and reconditioning of used sand. The ultimate solution is by no means yet attained, but sufficient progress has been made to convince the authors that the final goal will be reached in which used sand can really efficiently be sorted and separated, the largest proportion being first-class material for re-use.

Single sand practice is to-day being used in many shops. In some it has been tried and for very good reasons given up, the good reasons being that the quality of the castings has sometimes suffered. In the authors' opinion the fact does not condemn the process—it merely demonstrates that it is still in a partially developed state.

The day will come, probably quite soon, when we can control our sand practice as definitely as we control our steelmaking process. The single sand process is still probably of "the shape of things to come," but it represents, in the authors' opinion, the definite direction in which progress will be made, eliminating, as it does, the variation in returned sand which must exist where the practice is to use facing and backing sands of different quality. Great improvements will result from intensely accurate sand control on these lines—better castings and less dust risk. Furthermore, better castings in the sense of cleaner castings will lead to less dust risk in the fettling shop by a reduction in the amount of necessary grinding.

Hydroblasting of Castings

Turning now briefly to the hydroblast, it is probably common knowledge that experimental plants are being built for different parts of the whole foundry industry, ferrous and non-ferrous. Although hydroblast in a multiplicity of forms has been worked in the United States for many years, it has in every case been designed for a specific purpose. There is therefore no particular design suitable for general adoption in the jobbing foundries of this country, and consequently the usual teething troubles are likely to be experienced when the plants are installed.

Great credit is due to the works who are to experience these troubles, for their trials and tribulations are likely to prove of inestimable benefit to the foundry industry as a whole. Great claims have been made for this process, not only regarding its efficiency in cleaning castings, but also for its ability to cleanse the general foundry atmosphere, but the authors are not so foolish as to try to substantiate these claims without personal experience. Their reason for raising the matter is simply the fact that they see such enormous possibilities in this type of plant for achieving the twofold object of cleaning castings and reducing dust risk.

It is upon this slightly prophetic and optimistic note that the authors would close this section.

The authors wish to thank all those who directly or indirectly have helped in the compilation of this Paper. In addition, they would thank the directors of their company for the opportunities granted to prepare it.

Joint Discussion of Papers Nos. 774, 775 and 776

The following three Papers, presented to a session of the Annual Conference to which members of the Iron and Steel Institute had been invited, were discussed together:—

No. 774.—"Hot Tears in Steel Castings," by Charles W. Briggs (Technical and Research Director of the American Steel Founders' Society). (American Foundrymen's Association Exchange Paper.)

No. 775.—"The Continuous Production of Manganese Steel Castings from the Tropenas Converter," by L. W. Bolton (Member) and J. Hill (Associate Member), introduced by Mr. Bolton.

No. 776.—"A Wartime Steel Foundry—Some Problems and Developments," by E. Derek Wells (Member) and A. Johnson (Associate Member), introduced by Mr. Wells.

Paper No. 774 was introduced by the following note prepared by Mr. P. C. Fassotte. Mr. Fassotte was unfortunately prevented by ill-health from attending and the note was read by Mr. V. C. Faulkner (Past-President).

INTRODUCTION OF PAPER 774

It was with genuine pleasure that he presented and commended this year's American Exchange Paper, wrote Mr. Fassotte. The author's name was associated in foundrymen's minds with a most valuable series of contributions to the technique of steelfounding. When he heard that this Paper was forthcoming general expectations, therefore, were very high, and they have in no way been disappointed. The author had approached his subject in his characteristic manner, with a pertinacious search for the scientific explanation, yet never indulging in theory only, and never losing sight of the practical aspect; the same happy blend that made his previous Papers so acceptable to our industry where empiricism holds so much sway.

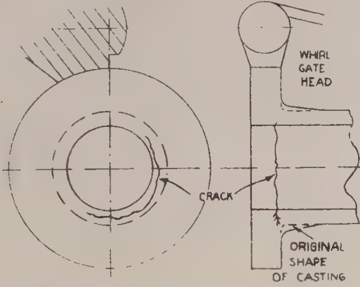
Of all the defects to which steel castings can be subject, hot tearing was the most pernicious, the most insidious, the most difficult to locate, and the most awkward to cure. For many years we were not fully cognisant of this defect, and were only aware of it when it was present in a blatant manner, say, in the form of a gaping gash on the surface of the casting. Only too often were foundrymen serenely unaware of the less discernible, fine, hairline crack, and only with the advent of magnetic testing and X-ray and gamma-ray investigation were they to be in the position of measuring the extent to which their products suffered from hot tearing. Prior to these methods of investigation, the industry was dependent on crude and inadequate processes of detection, such as sand-blasting after immersion in an oil bath, suspending castings on wires and relying on resonance to give an indication of soundness, or as a final resort, the always unfortunate method of sectioning a casting, and thereby destroying it. The non-destructive methods of testing were now enabling the steelfounder to become aware of the prevalence and magnitude of internal hot tears, to study their origin and thereby prepare the way for the remedy.

Non-destructive Testing

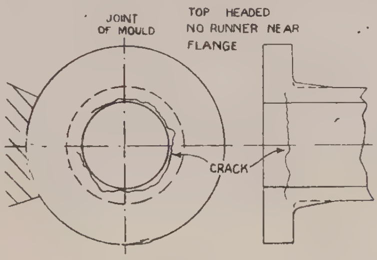
It was fortunate and timely that in the author's opening paragraphs he sketched the development of the non-destructive methods of testing in the United States. The picture he drew was impressive and well worth pondering over. It came at a particularly opportune moment, as X-ray and gamma-ray testing were so much in the forefront of the British steelfounders' preoccupations. The industry had undoubtedly been slow to move in this matter. Some founders have been viewing X-ray installations with suspicion, largely due to the fear that this method of testing might become an integral part of specifications and so increase manufacturing difficulties. This old-time attitude was that of the proverbial ostrich.

To-day the steelfounder was no longer happy merely because defects are not visible. A more enlightened view was now taken, and this change of opinion has been most rapid. X-ray testing was now considered as a help and no longer as a possible nuisance. The founder regarded it in the same way as the surgeon. He desired to be familiar with the inner structure and not merely with the outside. He required information on the location and extent of internal defects, confident as he is that his knowledge and skill would enable him to cure them. The steelfounder to-day was well on the way to considering non-destructive testing equipment as the indispensable adjunct of any steelfoundry. By drawing attention to the much more extensive use to which non-destructive testing was put in the States, the author had given an object lesson which was particularly welcome.

As the author explained, the formation of hot tears could not be disassociated from the presence of hindered stresses, and the analysis and origin of these stresses was extensive and convincing. The importance which was ascribed by the author to the ductility of the steel, which might even exceed the influence of strength at high temperature, was academically most interesting. To what extent, however, this fact could be applied was somewhat doubtful, as relative ductilities and strengths were bound to vary rapidly during the solidification period, and, in any case, were beyond calculation. Equally beyond calculation was resistance to contraction due to casting design, and nature of moulding materials. It was well known that different moulding media exhibited a varying proneness to the formation of hot tears. Certain sands had been known to cause more tearing troubles than others. One prominent British steelfounder had been attributing his freedom from hot tears to the use of a particular material which gave his moulds a high surface strength combined with a collapsible background. Mention might be made of the means whereby the resistance of the mould to contraction could be lessened and the practice often seen on the Continent of pouring water in pre-arranged cavities in the mould immediately after pouring, with a view of loosening the sand and preventing it from hindering contraction.



METHOD A.



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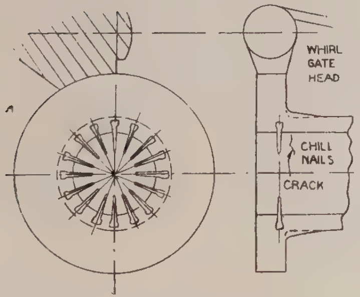

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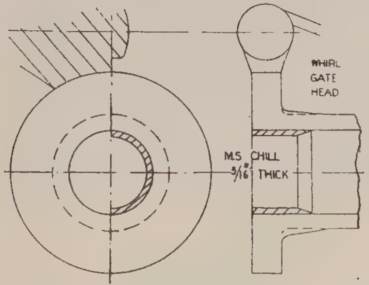


METHOD D.

A Practical Investigation

One British foundry a few months ago had a run of hot tears at the inside of a flange at the end of a particular casting. The matter was investigated most closely from every aspect, and in Figs. A, B, C and D some of the various methods of casting are depicted, including the method which, in the long run, proved to be successful, namely, a half internal chill in the bore of the cylinder. He (Mr. Fassotte) had had the opportunity to go through the results of these experiments and compare them with the author's conclusions. This comparison might perhaps be of some interest:—

(1) Both basic and acid steels were tried. Generally speaking, the behaviour was the same, though results with basic steel were slightly better.

(2) The carbon range of the steels used was between 0.2 per cent. and slightly above 0.3 per cent. Tears were equally persistent with all the carbon contents.

(3) The sulphur variation in the steels employed was between 0.02 and 0.037 per cent., with no noticeable difference in results.

(4) The phosphorus variation, between 0.02 and 0.04 per cent., gave no different behaviour.

(5) The steels were examined for non-metallic inclusions without yielding any information. Sections of defective castings have, however, been sent to the author and he may have a different opinion on this point.

(6) The widest possible range of practical pouring temperatures gave no indication that the casting temperature had anything to do with the formation of this particular hot tear.

(7) Different moulding media and hardness of ramming were tried without any result.

The foundry in question agreed with the opinion of the author that steels with low and medium carbon content did not behave differently from the point of view of hot tears, and with the contention that no special importance need be attributed to the pouring temperature. The temperature gradients in the metal did not seem to be affected in any material way by a variation of pouring temperature; it took an internal chill to upset this temperature gradient and put an end to the trouble.

After these extensive experiments the foundry was inclined to attribute the principal reason for the trouble to insufficient fluid head of metal at the moment of solidification. In view of the heads provided, however, this explanation might not appear too convincing and it would be interesting to have the author's opinion. It will be noted that none of the author's general conclusions was in any way invalidated by these tests. The author's Paper had done more. It had enforced clear thinking on an intricate subject. By his lucid analysis of causes and orderly marshalling of facts, he had dispelled many misconceptions and compelled the return to basic principles, a process always invaluable when dealing with a complicated issue. He (Mr. Fassotte) felt certain that he was voicing general appreciation as well as his own for a truly valuable Paper.

The Whirl Gate

Mr. W. B. Lake, J.P. (Past-President), said he thought the three Papers, to which he had listened with the greatest interest, pointed the way to a great improvement in steel castings. He had been very glad to hear Mr. Wells refer to the whirl gate head, because he felt that the industry had never sufficiently acknowledged the debt which it owed to the people who had invented it and who had thrown it open, free of charge, to the rest of them.

The Side-blown Converter

Mr. Malcolm Brown, in speaking on Paper No. 776, said that he liked the stimulating and cheerful way in which the authors flitted from one topic to another, but he was sorry that they had not enlarged a little more on the future of the Tropenas converter. If there had been as much works research put into steelmaking by this process as had been put into steelmaking by high-frequency, electric-arc and the open-hearth processes, it would stand higher than it did at the present time. He noticed that the authors touched very lightly on the question of the photo-electric system for controlling the Tropenas, but he thought that that had great possibilities. He had learnt, however, that the mouth of the vessel should be kept as wide as possible so as to obtain a good flame area. Smoke hoods should be kept as large as possible to avoid obscuration of the observation point by smoke and fumes.

No mention was made of the accurate measurement of the volume of air consumed on the heats. There was a great deal to be learned from accurate measuring methods.

Another point he would be very tempted to try was the use of conditioned air. If one considered the variation of humidity which arose in this country at different seasons of the year and converted it into the quantity of water actually flowing into the vessel, it would be of great advantage when it came to putting in a plant to control the humidity of the air. This had been done to some extent in America in blast-furnace practice, and those who had used it said that it had great advantages. If it had great advantages in making pig-iron it probably had great advantages also in making steel.

"L" Gates

On the subject of the whirl-gate head, he did not want to detract from the interest of the work which had been done, but he would like someone to tell him what the whirl-gate head really was. The use of the old "L" head with tangential runners had been common practice for many years in some foundries. He had thought that the novelty of the whirl-gate head lay in the narrowness of the part connecting the base of the head to the wall of the casting, and the close proximity of the head to such wall so that one did not get the freezing effect which was obtained with the "L" head. If the drawings in the Paper were to scale, then he would have said that the crank at the top right-hand corner was an example of the "L" head. But he wondered whether the drawing was actually to scale. If it was, he would anticipate trouble across the neck which was shown.

Mr. Derek Wells said that he thought the main point in these remarks calling for reply was the controlled air blast, and on that he agreed. There was no question about the truth of what Mr. Brown had said. One had so much coke and what one wanted was so much oxygen. Most of them would remember with a good deal of affection M. Deschamps, who died about eighteen months ago. He could recall him coming to his works and saying: "It is bright and frosty this morning, the humidity is low; you are getting a lot of oxygen in the air."

On the question of the whirl-gate head, he would ask Mr. Johnson to give his views on that subject.

Mr. A. Johnson said that, on the question of the "L" head, he admitted that this had been much used in steelfoundry practice, but not to the extent to which the whirl-gate head was being applied at the present moment. The whirl-gate head could be used on any portion of the casting without considering anything on the top at all. As for the crankshaft shown in the drawing, the drawing was to scale; the distance of the head from the casting was only about 1 in., or even a little less, as nearly as they could possibly tell. In that case he did not think there was any danger of the ingate freezing before the casting was fed. The smaller ingates were certainly used with this process, which he considered to be definitely a big advance on the older methods of the "L" head.

Inclusions and Hot Tears

Dr. C. J. Dadswell, speaking on Paper No. 774, said that he had enjoyed reading this Paper particularly, because it referred to a difficulty with which they were all very familiar. It touched on the methods which they had all tried to adopt for the prevention of hot tears. The author dealt with one factor, however, to which significance had not been generally attached, namely, the question of the amount of inclusions and the inclusion type, in relationship to hot tears. On reflection he thought it was perhaps confirmed by experience with certain types of castings in open-hearth steel as compared with electric steel, because in the former there was a greater tendency to tears.

He was of the opinion that the steelmakers' processes as used in the steelfoundries could be investigated still further. There had been a tendency to investigate them more from the point of elimination of blowholes and soundness rather than from the effect of inclusions. He felt sure that further fundamental examination of steel-making processes, and here he was thinking mainly of electric steel-making, would show that there was a further field of work. A few years before the war, a careful study of acid electric melting, with particular reference to temperatures during the steel-making process, led to findings which had had far-reaching results, particularly on the very subject of inclusions and their influence on resultant mechanical properties of the steel.

He was of the opinion that the people in this country had not yet learned all that could be learned about deoxidation. They had not always allowed for the conditions which might have to hold good in the bath, to give the slightly different conditions necessary at the time of adding different oxidisers. Therefore, some of these alternatives had been condemned, although if studied differently and worked out, they might have proved to be an advantage. The Americans were enthusiastic students of different types of deoxidisers.

The Whirl-gate Head

With regard to Paper No. 776, Mr. Malcolm Brown had already covered one or two points, in particular the question of the whirl-gate head. A Paper on this subject was presented to the local Branch in Sheffield, following which he made some remarks in order to clear up what he thought was a misconception regarding its function. He considered that this contrivance was one of the greatest advances that had taken place in the steelfoundry industry for many years past. The responsibility and credit for these improvements had not been properly placed, probably because there was not always a proper idea as to how the whirl-gate worked. It was not so much the tangential runner which gave the whirl-gate head its effectiveness, as the manner in which the head was attached to the casting to keep hot the connecting portion between the head and casting. In 1937, when visiting America, he saw a device which he called a "cut-off riser." In that country they were then using heads in which the connection between the head and the castings was only about one-third or less in area as compared with the head. This was done by a wafer-like core, which, because of its thinness, permitted the junction to be kept hot.

About two years ago, Mr. Basil Gray, with whom he was working, suggested a particular case in which that type of junction between the head and the casting might be applied. That casting gave an excellent result without the tangential runner, but with the connecting piece as described. A few months later Mr. Gray visited Hopkinsons' works and saw a tangential runner and "L"-head which was no more than an ordinary "L"-head, such as was commonly used either at the top or the bottom of a casting. Therefore, he would like to couple Mr. Gray's name with that of the other gentlemen mentioned in the Paper as those to whom a debt was owing for their pioneer work. It is certain that without Mr. Gray's research into its functioning and his enthusiasm for its application, there would not have been the wide use of the whirl-gate head now prevalent. A document written by Mr. Gray has been circulated by the Iron and Steel Institute, and shows a number of examples of castings which have been made by the whirl-gate head method.

As regards the atmospheric riser which adds to the advantage of the whirl-gate head, he saw this being experimented with in the U.S.A. 12 months ago, just at the time of the publication of its details. It was applied to what he calls the "properly placed 'L'-head"—that is having a close connection and without the tangential runner. This brings to mind two important points—the fact that simultaneous development was taking place on both sides of the Atlantic, and again that it is not the runner so much as the position of the "L"-head which is so important. A point that Mr. Basil Gray has been responsible for developing and publishing.

Finally he wished to refer to the other subject which Mr. Wells and Mr. Johnson had mentioned, namely the Hydroblast system. He was sure that every steelfoundry would end by having something closely related to the Hydroblast system because of the immediate benefits which resulted from the washing and reclamation of sand.

MR. DEREK WELLS said that he knew that there had been a great deal of questioning as to why the whirl-gate head worked as it did. Perhaps the final answer to that question was not yet available. Not until the Paper by Taylor and Rominski was published was it seen how the whirl-gate head worked. Those authors pointed out that the temperature gradient between the head and the casting was more important than pure gravity, and if that was not the whole of the answer it went a long way towards supplying the answer. With regard to the Hydroblast, this might be a case where the by-product proved in the end more important than the main product.

Standardised Nomenclature

MR. C. H. KAIN, referring to Paper 775, thought the development in a short time of such an excellent technique, reflected very great credit on Mr. Bolton and Mr. Hill. He well remembered the day in August, 1940, when Mr. Gardom showed him a roofless, derelict building without power, water or sanitation, which he (Mr. Gardom) was about to convert into a production steelfoundry. In less than eight months (March, 1941) he had had the pleasure of being present when the first steel was blown during a howling snowstorm in the still uncompleted building. That was a day of notable memories, not the least being of Mr. Fitz-Herbert Wright starting his career as a steelmaker by punching out the converter tuyeres which he (Mr. Kain) had allowed to become frozen.

Since that day the plant had made great progress, a good deal of which was due to the methodical tackling of steel-making problems by Mr. Bolton and Mr. Hill. Converter practice was capable of reduction to very exact mathematical limits, and he had been very much concerned about the time which appeared to elapse before the flame appeared. Then it had dawned on him that what the authors called the flame some others called the boil, and he would like to ask Mr. Bolton and Mr. Hill to clarify this matter, because if there was a difference in terminology it would make the data very difficult indeed to compare. In his own case, the "flame" appeared at a constant time of about 5 min., but the "boil" appeared at a variable time, and it would be useful to get the terminology standardised.

The temperature readings given in the Paper were extremely interesting. The range of temperature quoted which he had previously suggested was the difference between sluggish steel and lively or hot steel, and he desired to know if the steel from the vessel at 1,540 deg. C. was considered sluggish and that at 1,580 deg. C. was considered hot and fluid? This would be an interesting sidelight on the argument as to the relative life of basic electric steel and converter steel. He, personally, contended that this was very largely a matter of temperature.

It was extraordinary to notice that increased manganese did not erode the lining of the converter. Most operators had found that an increase of manganese in the charge metal of the vessel over about 0.6 per cent. caused excessive erosion of the lining.

He was disappointed to find that the blowing angle was adjusted according to the appearance of the sparks escaping from the converter mouth. He considered that that was bad practice. If one standardised one's practice one should stick to it, and if a blowing angle for a certain charge had been agreed on, that angle should be applied with every charge, and one should not juggle about with it.

Factors Affecting Life of Linings

He desired to ask a question regarding the drying of the vessels before use. He had a little information which, unfortunately, owing to shortage of labour, he had not been able to follow up. The data he had collected, however, did indicate that the longer a rammed vessel was air-dried before use the better the lining life obtained from it. With an air-dried vessel one could safely expect a life of 110 to 120 heats. He wished to ask if the authors had any actual information on that point.

With regard to the addition of sand to prevent lining wear, it was not quite clear whether sand was added after every blow or only once per shift or once per day. In his own case he had abandoned this practice because he found there was an actual building up of the lining which kept the output of the vessel constant. His own output and timetable were based on the assumption that if one started with 25 cwts. on Monday, one should get to 35 cwts. by Friday or Saturday. Therefore in this case it actually resulted in a reduction of output and the method of adding the sand to the converter before blowing had to be abandoned. At the end of the Paper a cupola loss of 7 per cent. and a converter loss of 12 per cent. were recorded, and this total loss of 19 per cent. he considered excessive. With good practice an overall loss of not more than 15 per cent. should be experienced.

Paper No. 776 was very interesting and a great credit to Mr. Wells and Mr. Johnson. He would be glad to discuss it at greater length when he had had an opportunity of studying it with more leisure. They referred to the varied state of oxidation at the end of each blow and to the difficulties encountered in keeping sulphur and phosphorus low. If the composition and temperature of the cupola metal were standardised, the oxidation conditions at the end of the blow should not be variable. Variable oxidation conditions resulted entirely from juggling about with the vessel, such as "moving into or out of the wind," according to the appearance of the spark at the vessel's mouth, which was bad practice.

Whirl Gate Results

He congratulated them on Table I, in which they gave all the results and averages and also the maximum and minimum. He was very pleased to note the appropriate reference to the whirl-gate head in this Paper, and he could not agree with Mr. Brown that it did not show any radical departure from the old "L" head. They had all used the "L" and angle heads for many years, but the technique of applying the whirl-gate head in angle form had undoubtedly been developed by Davenport and Speakes. Although there was nothing new in the actual outline of this head, the application and technique of the present use of it were entirely due to them.

One of the advantages which they claimed for this method was an increase in yield of casting from liquid steel obtained by feeding 2, 3 or 4 small castings from one centrally placed whirl-gate head. In his own case, however, that had been a complete failure. The castings were not clean. If four castings were used, two of them, or usually even three, were dirty and tended to scab. He had had very poor results from trying to get two or three castings from the same head in green sand. Perhaps better results might be obtained with dry sand.

Sand Bonding Difficulties

The reference to the bonding difficulty was of interest, and although he had not had an opportunity of comparing the authors' remarks with his own experience, they seemed in general to agree on various points that Fulbond was an excellent bond as such, but not a good bond to use repeatedly. Fulbond had good strength, but low fusion point. It tended to ball up, and if it was to be used successfully, one must make large additions of new sand. He was faced with the problem when using Fulbond which is a native material, of obtaining adequate supplies of new sand, which was very difficult owing to the restrictions on transport. On the other hand, imported bentonite enabled one greatly to reduce the amount of new sand consumed in the foundry. Fulbond yielded excellent results in green sand and for small steel castings provided the consumption of new sand was heavy.

Could any data be given as to the amount of new sand it was necessary to consume in order to maintain the highest quality in the castings? He, himself, gave some figures sometime ago in which he suggested that the increase was of the order of 25 per cent., but that was a very conservative estimate. The amount of new sand consumed as against bentonite bonding was, in his case, about double. This naturally depends upon the initial consumption of new sand per ton of castings produced.

The Dust Problem

He thought that the dust problem was greatly accentuated by wartime conditions and the worry and debility under which everybody was at present suffering. Nearly all his own people were told by the doctor to have a few days in the fresh air and then start again. The present was not a good time to study the dust problems, because not only were such problems accentuated by blackout and artificial lighting, but also there was a less skilled type of labour living under difficult conditions. Their physical condition, which was poor initially, was made worse by worry and wartime food and so forth, and the problem assumed an importance altogether out of proportion to its real value.

He was rather surprised to notice that there was no reference to the question of maintenance. This was the most important problem before any foundry which was production-minded at the present time. They could obtain numbers of people who could repair, but few who could maintain. That was a problem even in peacetime, but in wartime it was accentuated by the increase in working hours of the plant and machinery, and by the poor quality of the people with whom they had to deal. Also, with the advent of higher wages, the maintenance people only wanted to work short hours, come in late, and go home early. Maintenance was the greatest problem facing the production foundry to-day.

Significance of Temperature Readings

MR. L. W. BOLTON thanked Mr. Kain for his comments. Dealing first with his point on nomenclature and the question whether the flame appeared earlier in the blow than was stated, the experiment carried out proved that carbon did not oxidise appreciably until the silicon had fallen to the region of 1 per cent. The oxidation of carbon was the only reaction which would produce a flame and, if the silicon was high, a considerable time could elapse before the appearance of a flame. Sparks and hot gases appeared before this, but the only flame was the carbon flame.

With regard to the point on temperature readings, the figure of 1,590 deg. C. quoted by Mr. Kain was actually taken on the converter bottom after the steel had been teemed. The steel was undoubtedly hotter than this, as there was inevitably some loss of temperature from the converter lining before the reading was taken.

It was mentioned in the Paper that, with a temperature reading on the converter bottom of 1,550 deg. C., the actual metal poured into the first casting usually had a temperature of 1,510 deg. C. The steel from the converter, therefore, must be considerably above 1,550 deg. C., because 21 per cent. of lower temperature metal was added in producing the manganese steel, and also some time interval elapsed between the taking of the two readings. The main point, of course, with regard to the fluidity of manganese steel was that its melting point was considerably lower than that of carbon steel, so that normally, when produced by the process described, there was plenty of temperature in hand.

Lining Erosion from High Mn Content

With regard to Mr. Kain's query whether increased manganese did not add to lining erosion, he would not care to be dogmatic on this point. Using high manganese metal in the converter, there was a very considerable quantity of fluid slag formed, which would suggest that an increase in lining erosion might be expected. The experience gained on a limited number of heats was that there was no serious increase in lining erosion, but perhaps insufficient experience was available to be very definite on this point.

On the question of the angle at which the converter should be blown, he agreed with Mr. Kain that 15 deg. gave the best results. On the other hand, with continuous operation, where an interruption in the melting programme could cause a hold-up in the moulding section, this angle could not always be strictly adhered to. If for some reason the metal charged into the converter was a little short, there was sometimes not time to bring up a little more metal, and as long as the metal available was somewhere very near the ideal amount, a smaller blowing angle could be used with satisfactory results. The same applied if a little too much metal was charged, and it had been found that a few degrees either way in the blowing angle was not of very great importance.

Air-dried Linings

Regarding the air-drying of linings, experience was definitely that a lining which had been air-dried for seven to nine days gave superior results over a lining which was rammed up and used immediately. He was interested in Mr. Kain's remarks with regard to the addition of sand and his experience closely followed Mr. Kain's. If too great an addition was made, there could be a considerable build-up on the lining and the addition must be controlled to avoid this.

Mr. Bolton agreed with Mr. Kain that a total loss in the cupola and converter of 15 per cent. should, under normal conditions, be considered high. On the plant in which these observations were made, the production was very considerably higher than that for which the plant was originally designed. Because of this, the converter was being pushed to give rapid heats and the cupolas also were being worked at a higher rate than would be regarded as ideal for the type of charges melted. If a longer time could be allowed in obtaining heats from the converter, and if the cupolas could be operated with a softer blast on a reduced output, he was confident that losses could be reduced.

The Effect of Dust

MR. DEREK WELLS said that he would prefer to answer most of Mr. Kain's remarks in writing, but there were one or two points he desired to mention. Mr. Kain stated that the effect of dust had been found mainly in the case of the casual wartime labour just brought into the works, and that therefore the solution of this problem was mainly a matter of waiting until more normal conditions returned. With this he disagreed very profoundly. His own experience was that the various ways in which dust was affecting people were shown most markedly with men who had been working with them for ten or twenty years. Although this was probably not the time for a large national investigation into the matter, it was a problem to which foundries should devote their attention as soon as times were a little easier and happier.

With regard to sand in converters, they had also made experiments on that point and their experience was exactly the same as that of Mr. Kain's. When the matter was put to him originally it was claimed that it would prolong the life of the tuyeres, and in their experience the tuyeres were the first part of the lining to go. They obtained an average of 100 heats to a set of tuyeres, and it was a small matter to cut out what was left of the tuyeres, replace them, and go on for another 70 or 80 heats. They had gone as high as 1,000 tons by that means. His experience was that the addition of sand to the metal charged did not improve the life of the tuyeres at all, but rather lead to excessive "building up" of the lining and so causing a reduced capacity.

Hot Tear Susceptibility

MR. W. H. SALMON, speaking on Paper 774, said that the author had provided an excellent summary of the published information on hot tear formation in steel castings, and referred to the remark near the end of the Paper that some type of foundry test must be developed for hot tear susceptibility.

However, it was not easy to obtain a numerical index of the tendency to hot tear. Foundrymen all over the world have attempted to design test castings for this purpose, and he wondered if the author could say if any recent work had been carried out in America on this subject. The form of test should be designed with three aspects in view; first, it should be cheap to mould; secondly, it should give reproducible results, or if it is cheap enough to mould, a large number of results could be averaged; thirdly, it should give a numerical value of the tendency to hot tears in order to show the influence of the following three variables:

(*a*) *Casting Temperature.*—His opinion was that for a given design of casting there was an "ideal range" of pouring temperature. At casting temperatures below this range trouble is encountered by cold lapping, scumming, entrapping of air and foreign particles, and lack of internal fluidity which may give rise to unsound internal areas. A large proportion of foundry wasters could be attributed to the use of molten steel which was lacking in fluidity or running power. On the other hand, casting temperatures higher than the "ideal range" for any particular design, imposed a more severe action on the moulding sand, but he had not yet been able to prove whether rather higher temperatures were as serious as they had been thought to be in causing hot tears, except in the case of alloys such as Hadfield's manganese steel, which gives a gross crystallisation when cast too hot.

(*b*) *Steel Composition, Method of Manufacture and Types of Inclusion.*—He agreed with the author that sulphur was the element which caused most trouble in causing hot tears, and had found in certain cylindrical thin-walled castings that above 0.030 per cent. S there was almost a straight line increase in the percentage of "pulled" castings, as the sulphur content increased to 0.060 per cent. Below 0.030 per cent. S there was no trouble with simple designs, but with more intricate designs it was advantageous to keep sulphur as low as ever possible. With regard to the author's comment that lower carbon steels were less liable to hot tears, he was interested to read this confirmation of a recent experience with an intricate casting which showed considerably less hot tearing when the carbon content was in the range of 0.15 to 0.18 per cent. than when it was up at 0.25 per cent. C. The steelmaking difficulties are increased with the lower carbon ranges. He was surprised the author had not referred to the beneficial influence of silicon and copper on the tendency to hot tears, and he had a feeling that, as there appears to be no loss of ductility in the physical properties of steel castings if the carbon is reduced *pro rata* as the silicon content is increased, the author may have pointed the way to an advance in "steelmaking for the foundry" which would be most effective in limiting hot tears.

(*c*) *Sand Strength at High Temperature.*—The introduction of oil sands which readily collapse after casting and the recent work on the high temperature strength of clay bonded moulding sands were indications that the problem of sand properties was being considered continually by the foundryman, but he sometimes wondered whether "high temperature tests" could really reproduce the conditions which exist in the mould just after casting when the "hot tears" occur. The adoption of a standard "hot-tearing" test-piece design would be of great assistance in studying the practical aspect of sand strength in relation to hot tears.

Finally, he would like to refer to the sketches, Figs. A to D in Mr. Fassotte's notes, which showed that while a change of running and risering, and the use of internal (horse-nail) chills had been ineffective, the hot tears had been eliminated by means of a light external chill in the core. In many cases external chilling is the only means the foundryman can employ to overcome the tendency to hot tears. Every chill has to be specially shaped, cleaned and recovered after use (if possible), and many of these chills could be avoided if the foundryman and designer could be brought together while the job was still on the drawing board.

MR. COOPER said that hot tears were caused particularly by carelessness in moulding and running. It was found that in making castings they had to be very careful to use a uniform thickness of sand, and where the casting was heaviest they cut down the sand as much as they could for quick cooling. In addition to that they took great care to stop any flash in the runner and in the riser, and in the section where the boxes were closed. He just mentioned these things in passing so that anybody who was working on these lines could look to see whether the melting was sufficiently good to prevent any fault. Another mistake which was sometimes made was the use of sand which was rammed too hard.

Electrically-heated Holding Furnace

MR. BOLTON said he quite appreciated the advantages in the production of light castings in having an electrically heated holding furnace, and the combination of an electric furnace with a holding furnace had been in mind when drawing the comparison to which Dr. Dadswell referred. He did feel, however, that with an electric furnace alone, without a holding furnace, the cost of the installation would be considerably higher than that of a cupola-converter plant. Attention was drawn to this in the Paper, partly with the idea of stimulating someone to write a similar Paper from the electric furnace user's viewpoint, and it would be extremely interesting to see how the production costs actually compared.

Order of Importance

MR. F. W. ROWE, B.Sc., said that, on Paper No. 774, all that he had to say was very largely in corroboration of what other speakers had said. They were indebted to Mr. Briggs for his Paper. It was focusing attention on a somewhat neglected suoject. He supposed that at the present time they had so many problems in front of them in steelfounding that it was difficult to put them in their right order of importance and to say which should be tackled first, but to his mind there was a great deal to be learned about hot tear formation in steel castings. It was nearly as great a source of trouble as shrinkage to which most of their endeavours had been directed. In that respect, he hardly thought that Mr. Briggs placed quite enough emphasis on the influence in steelmaking of the formation of hot tears.

He had had in his time one or two bitter experiences of hot tear formation, and apart from this awkward business of design, with which they were all familiar, there was no doubt that steelmaking practice had a very large influence on whether a difficult casting was going to show hot tears or otherwise. He had had a 12-ton heat of electric steel where the whole of the castings were full of hot tears from start to finish owing to errors in the refining process, and it made one realise how much one was dependent on correct steelmaking practice and also on correct control of temperature both throughout the steelmaking process and in casting.

He was glad that Dr. Dadswell had called attention to the radiographs illustrating the Paper. Those who had had any experience of radiography knew this type of defect was often revealed and had been ascribed to various causes. This type of defect was so often not revealed in machining, and the operations should be investigated in greater detail than was usually the case in order to discover whether some clue could be given to the causes. The question of slag inclusions was also important. In most steelmaking processes, however, one was torn between two fires. The defect of which they were all most afraid was gas holes due to hydrogen liberations at the moment of solidification, and that type of deoxidisation additions which obviated this defect might produce a steel liable to hot tears.

Freedom of Acid Steel from Hot Tears

MR. W. H. SALMON, speaking on Paper 774, said that he was interested in Dr. Dadswell's description of an internal defect in a steel casting 3 ft. 6in. dia. by 4 ft. high (head 2 ft. dia.), which had been cast vertically, because he had seen similar defects in the riser or immediately below the risers of heavy steel castings. There was no sign of the defects on the surface, machining showed that they commenced several inches below the surface and extended across the centre of the casting, sometimes just one horizontal layer, and sometimes there were two arrow head formations inclined upwards towards the centre. He had seen the defect in basic electric and open-hearth steel, but had not yet seen it in acid steel unless the steel had been very cold. It was probably due to the formation of a film or scum on the surface of the molten steel as it was rising in the mould, over which later steel flowed, thus trapping the film of crystallites in a horizontal layer which tended to seal off adequate feed metal from the zone immediately below it.

Probably this type of defect was really an internal cold lap. A similar defect was seen in large ingots which had not been cast quickly enough, the internal breaks in the upper portion being revealed in forging. As these internal discontinuities did not come out to the surface he would prefer to call them "internal freezing or shrinkage defects," and while admitting that a hot tear which was revealed at the surface could be due to the fault of the moulder, he could not see how an internal cold lap could be attributed to the moulder unless he had run the job too slowly. Once a solidified skin of metal 2 in. or 3 in. thick had formed, he could not visualise how the fluid steel inside the envelope could "hot tear," but realised that shrinkage defects similar to those shown in Fig. 11 could form if insufficient reserves of fluid metal had been provided in the risers, or the feeding had been ineffective because of the earlier freezing of intermediate layers.

In conclusion, he would like to pay a tribute to the author for this stimulating and comprehensive Paper he had presented on behalf of the American Foundrymen's Association.

MR. B. SKIDMORE, speaking on Paper No. 774, agreed with Mr. Cooper that the majority of hot tears were caused by carelessness, but also from dozens of other causes as well, most of which, however, were rectified by the ingenuity of the foundryman. The problem of hot tears and cracks certainly went deeper than that. What the foundryman would like was more knowledge of what actually happened when a casting starts its contraction, even on a casting of equal section. A question often raised by young moulders was: Did an external hot tear start from the inner section when in a stiff pasty state or is it torn through the already solidified wall? A second was: Did a cavity have the tendency to cause a hot tear leading from a cavity to the outer wall? A personal answer was in the negative. It was quite true that foundry people did encounter tears which led to a cavity, but it was far from being the general rule, although it was claimed by many to have some connection; he thought otherwise.

Sometime ago one firm had a casting returned which had cracked after being in service some considerable time, and when it had been sawn through for inspection it did show a small cavity. The question arose as to whether it was a hot tear which was not seen by the inspection department or not. After many consultations the foundry manager was still not satisfied, and made more inquiries as to what actually happened to this casting, and found out that this casting had had a terrific smash. The casting had actually been broken. The results of the further inquiry was no torn casting. Of course, preparations were made to overcome the cavity and proceed with the job. No foundryman liked to find hot tears in any casting, and used many varied methods for eliminating them and keeping within safe limits; small V-shaped tears can and should be successfully repaired.

Mr. Cooper asked whether it would not be possible, when the inside of the casting was liquid, to have a hydraulic pressure.

The Chairman (Mr. J. W. Gardom) said that he wanted in particular to thank Mr. Fassotte for his excellent introduction to the American Paper. He did not remember an overseas Paper being introduced quite so well as this one. Evidently a great amount of time had been put into Mr. Fassotte's note. The question had arisen as to what was a hot tear and when did the defect start. The Technical Committee, through various sub-committees, had tried to bring out from time to time an atlas of defects—illustrations of what was meant when certain defects were described. This would enable the descriptions in individual Papers to be better understood. Different sub-committee reports dealt with cast iron, with steel, and with non-ferrous metals, but it would be better to have a committee to deal with the whole subject, because, after all, it was all foundry work, and many castings defects were common to all three types of material.

Vote of Thanks

Mr. Rendall proposed a vote of thanks to the authors of the Papers, which he said had covered an immense field. This question of hot tears had gone to the fundamentals of temperature and temperature gradients. The other two Papers had also been masterly. The Paper by Mr. Wells and Mr. Johnson gave a review of how to apply the knowledge now available, and stressed the necessity for standardised practice. He knew that he was speaking for everyone present when he expressed their thanks to the authors for the instruction they had afforded.

Mr. Speakes seconded the vote of thanks, which was accorded by acclamation.

Mr. Faulkner replied to the Chairman's felicitous remarks with regard to Mr. Fassotte's introduction. He said that twenty years ago he himself had with others initiated this system of international exchange Papers, of which Mr. Briggs was so excellent an example. There had now been several hundreds of these Papers exchanged throughout the world, constituting a veritable library of foundry technology. The Paper by Mr. Briggs enhanced the very high regard which British foundrymen had for the research work published by its author.

Mr. Bolton and Mr. Johnson also expressed their acknowledgments of the vote of thanks, and the meeting then terminated.

WRITTEN CONTRIBUTIONS

Paper No. 776

Mr. E. J. Kelly wrote, on Paper No. 776, that mention of the whirl-gate head and atmospheric head was of particular interest to the steel-foundryman. The castings made by this method were of sharper detail; they were not disfigured by the many various types of head usually associated with these castings. Another useful feature with their use was that the mould and core material had only to stand up to the actual volume of metal needed to fill the mould proper. The head metal did not enter the mould; therefore there is less erosion on mould and core. Had the authors any data on the relative qualities of the whirl-gate head and atmospheric head on similar types of castings?

With reference to the sand problems, sustained effort had to be made in the steelfoundry at the present time to achieve good results. The nature of the bond claimed close attention. When scabbing or erosion had occurred, portions of oil-sand core may usefully be employed in such places. This practice might also be applied where the authors say it had occurred when the runner had had a scoring effect. The runner itself might be in core with good result.

The use of proprietary core compounds are with advantage used as a bond in many facing sands in the steelfoundry. The stripping qualities were excellent. But it had a much greater destroying effect on the sand mass as compared with a clay-bonded sand. Had the authors a similar experience of such uses?

Dealing with the question of dust, this was a most troublesome problem in the foundry, and the authors could be assured they were not alone with the problem; every effort was being made to solve it by methods as suggested in the Paper. Watering the floor is a very old and useful method to employ, since at least it arrests the floor dust, so readily kicked up by all. Much remained to be done, however, since this was one of the chief causes of absenteeism. Anything that could be done to alleviate the trouble will serve a most useful purpose to the foundry.

Dealing with the question of a single or synthetic sand, much useful experience and data would probably be gained from the foundries now employing this method on mass production work. Whether it could be applied with advantage to the jobbing foundry only time could tell. But it certainly suggested its usefulness and was well worth persevering with. The writer agreed with the authors on the conclusions they had reached on this matter.

Authors' Reply

Mr. Derek Wells and Mr. Johnson wrote thanking Mr. Kelly for his trouble in so setting out his remarks and regretted that they could not answer his two questions more fully.

Regarding the atmospheric head, the authors had merely made sufficient progress with it to visualise its possibilities, but they could not offer any comparative data between the application of this type of head and the one generally spoken of as the whirl-gate head. They were rather inclined to the view that these would gradually be merged into a "hybrid," bearing, it was hoped, all the advantages but none of the disadvantages of both parents.

Mr. Kelly's remarks on the use of oil-sand cores for runners were very apt, and either they or refractory sleeves (they each have advantages dependent upon other factors) should be used with green sand. They were not quite clear as to Mr. Kelly's comments on the "destroying effect on the sand mass of core compounds." Naturally, under the influence of the pouring temperature of the steel, these organic compounds break up, and they had little or no value afterwards from a reclamation point of view.

MR. WELLS and MR. JOHNSON also took the opportunity to add the following remarks to their verbal reply to Mr. Kain.

Mr. Kain said he had not had the same experience as the authors regarding the feeding of two, three, or four small castings from one centrally placed whirlgate head, and that he thought that this might be attributed to the use of green sand by himself as against the employment of dry sand by the authors. They felt that in this respect Mr. Kain might be right, since the examples of this use of the whirl-gate head quoted in the Paper were derived from dry-sand practice.

Mr. Kain said he had not had the same experience of Fulbond, and to reply to this fully would take up more space than was available; but, briefly, they would inform Mr. Kain that their support for the efficiency of Fulbond was based on their practice of using it as a substitute for bentonite in increasing the compression strength of moulding sand. To be more precise, they had not had as much experience as Mr. Kain in reclaiming 80 to 85 per cent. of the sand used in the foundry, and therefore on this point they must accept the experience of Mr. Kain that Fulbond does not have such a good "life" as bentonite in that it calls for very much bigger additions of new sand to each batch milled; just as in the past they had used bentonite to strengthen the moulding sand for heavy castings of some tons in weight, so they had found Fulbond an adequate substitute. They therefore felt that this was another case where their findings might differ because their use of the material in question was also fundamentally different.

The authors appreciated very much Mr. Kain's comments on the question of foundry maintenance, and the fact that they did not themselves comment on this problem in their Paper must certainly not be taken to mean that they regarded the matter as insignificant. The authors agreed entirely with Mr. Kain's remarks and had themselves had the same experience. The shortage of really skilled maintenance men, together with the fact that most foundries had added considerably to their mechanised plant during the war has, it must be agreed, made very difficult the question of preventive maintenance. The authors wished to state how very strongly they felt regarding the need for such preventive maintenance rather than regarding one's millwrights, electricians, etc., merely as a breakdown gang.

Desulphurisation with Basic Linings

In a supplementary note, the authors clarify their reference in the Paper to the question of desulphurisation. In the section on desulphurisation with basic linings, they conclude with the statement covered by figures in Table II to the effect that the desulphurisation achieved from the patched lining was only a little better than that obtained from the former type of lining used. Some prolonged trials showed that the results obtained with the material Dolopatch were quite as good as those given by the parent lining, and in consequence the authors are quite unable to account for the rather freak results on which the statement referred to was based. The tests made did not show that Dolopatch is not as satisfactory as the original lining.

The authors also give the following figures obtained with Dolopatch patching on top of a Dolofer block lining on three days last July:—

July 14.	July 16.	July 19.
0.033	0.032	0.033
0.041	0.040	0.033
0.044	0.035	0.036
0.041	0.042	0.031
0.032	0.037	0.035
0.037	0.036	0.032
0.035	0.036	0.030
0.034	0.043	0.031
0.036	0.032	0.030
0.035	0.031	0.035
0.032	0.035	0.035
0.031	0.034	0.032
0.039	0.035	0.034
0.034	0.041	0.036
0.040	0.034	0.031
	0.036	0.037
	0.035	0.033
	0.037	
Av. 0.036	0.036	0.033

Written Discussion on Paper No. 775

MR. P. C. FASSOTTE wrote that Paper No. 775, had made such good reading that he was tempted to make a few remarks. The authors state that it is desirable to fettle the nose of the converter, as otherwise the blast volume increases and determines a greater oxidation loss. Previously, however, they mentioned that the blower which is used is of the positive type. With such a blower the volume of air delivered is independent of back pressure and, consequently, the size of the nose cannot influence oxidation losses. They are correct, however, in stating that an over-sized nose tends to increase losses due to ejections. With a fan, the volumetric output is influenced by the amount of back pressure and, theoretically, a wider nose should lead to a greater admission of air in the converter; the difference, however, can only be small, and it is very doubtful whether this would affect oxidation losses to any extent.

A certain amount of confusion exists about this question of volumes and pressures used in conjunction with converters. The chemical reactions which take place in the vessel call for a large amount of oxygen and are intended to achieve the double purpose of eliminating certain elements and increasing the bath temperature. A metallic loss is incurred thereby, partly chemical and partly physical. The first is unavoidable, but the second is largely controllable.

As heat losses are a function of the duration of the blow, it is desirable to shorten the blow and concentrate the reactions in a short period. Incidentally, this favours economy of silicon. The total volume of air required by the blow should, therefore, be introduced in the converter in as short a time as possible. Obviously it is desirable to have a positive control over this input, and this is the great argument in favour of the positive blower. Such an equipment, provided it is of sufficient capacity, gives full control of the volume input, irrespective of frictional losses and back pressure.

Having this control of volume, the limiting factor of the speeding up of the operation becomes the physical metallic loss through projections. The amount of these projections is principally determined by the carrying capacity of the blast, which in turn is determined by the velocity of the blast, and this velocity is a function of the pressure at which the air is travelling at the exit of the tuyeres. It is only at the tuyere end of the air circuit between the blower and the converter that the final pressure can be altered and the velocity of the air influenced, since the frictional losses in the pipes can, for practical purposes, be considered as constant. Low pressures in the tuyeres mean low velocities and low projection losses. The design of the tuyeres, and particularly their total area, is the main factor governing the rate of air input practically possible, the duration of the operation and the amount of physical losses.

What induces these remarks is the figure of 12 per cent. which has been put forward as converter loss. The authors have, however, experienced, under certain conditions, a loss of 10 per cent. only. They obtained this by reducing their pressure, but as they at the same time reduced their volume, the operation lasted 20 min. He was not convinced that this produced steel of greater temperature; the opposite should have taken place, as the heat losses were bound to be greater with the longer operation. They have observed, however, that the metallic loss was smaller when using a low pressure and this was to be expected.

Probably the most severe criticism that is levelled against the side-blown converter is the high metallic loss entailed by the process. Scope for economy in this direction is vast indeed. The unavoidable loss is the weight of carbon, silicon and manganese in the iron. For the composition of iron mentioned by the authors this figure amounts to just over 5 per cent. The margin of possible economy in this case is, therefore, in the neighbourhood of 7 per cent. Part of this cannot be prevented on account of the law of mass, but a very substantial inroad can be made into this figure. In fact, plants are now in operation where the losses experienced in the converter have been brought remarkably close to the theoretical loss. These results have been obtained by a combination of plant design and converter practice, both based on a proper understanding of the interlocked factors of volume, pressure and velocity, and their influence on metallic loss.

Authors' Reply

MR. L. W. BOLTON and MR. J. HILL, in a written reply to Mr. P. C. Fassotte, thanked him for his interest in the Paper and for his very useful comments. In the plant described, the blower delivers a positive and known volume of air to the converter for only a very small part of each heat. For a large proportion of the total blowing time, amounting to as much as 90 per cent. of some heats, the relief valve is opened to a greater or lesser degree because the use of the full air supply would cause too great a loss from ejection. In these circumstances, the conditions under which the air is supplied are similar to those obtaining when a high pressure fan is used, that is, an increased resistance in the vessel causes more air to pass through the relief valve and less into the conveter, and vice versa. In other words, in spite of the use of a positive blower, the back pressure in the vessel does influence the volume of air admitted.

Mr. Fassotte's suggestion that control should be maintained over volume input while still retaining the positive nature of the blast is noted with interest, and the authors agree that the provision of such equipment might be advantageous. They agree also with the remarks on tuyere size and its influence on air velocity and metal losses and intend to take an early opportunity of examining this further.

The metal losses experienced in the plant at present are admittedly on the high side, though in the opinion of the authors they cannot be considered in any way excessive under present conditions of operation. It is again stressed that the output from the plant is approximately 50 per cent. higher than that for which it was designed. It is believed that, if it were not necessary to obtain such rapid heats from the converter, losses could be reduced using the present design of vessel.

So far as the cupolas are concerned, the melting loss averages 6 to 7 per cent., which, again, may be a little higher than that obtained when melting similar mixtures in other works. On these furnaces, attempts have been made by increasing tuyere size and reducing blast velocity, to reduce oxidation, but the output required is extremely high for the size of cupola when melting high steel charges, and the steel scrap available is often of a light, bulky nature which it is difficult to melt rapidly while keeping oxidation losses low. Under existing conditions, it does not appear possible to improve very materially on the results from these furnaces.

In a later written reply to Mr. C. H. Kain's contribution, with reference to the question on the time allowed for air drying of the converter lining and its influence on subsequent lining life, Mr. Bolton gave the figures below in confirmation of the statement made by the authors that a drying time of seven to nine days is beneficial. It will be noted from data given in the Paper that the average life of a lining used after air drying for nine days is 122 heats. Shorter times than this have been allowed for drying from time to time using the same lining methods and materials, with the following results:—

Number of days lining air dried	Number of heats from lining	Average number of heats
5	127	118.7
5	141	
5	88	
4	134	111.7
4	90	
4	111	
3	101	88.7
3	84	
3	81	
2	61	66.3
2	66	
2	70	
2	70	
2	66	
2	65	

It is possible that drying time could be reduced, without any deleterious influence on life, if warm air were circulated inside the newly-lined vessel, but in the ordinary foundry atmosphere seven or more days' drying is necessary to obtain the most satisfactory results.

Written Discussion on Paper No. 774

MR. W. T. BRUCE wrote in reference to Paper No. 774 that if, in the not very distant future, the X-ray examination of pressure castings is enforced by a clause inserted in the existing specifications, foundrymen and metallurgists would meet with problems which, compared with their present ones, would be like the proverbial mountains against the molehills.

[Mr. C. W. Briggs' reply to the discussion on Paper No. 774 will be found on page 289.]

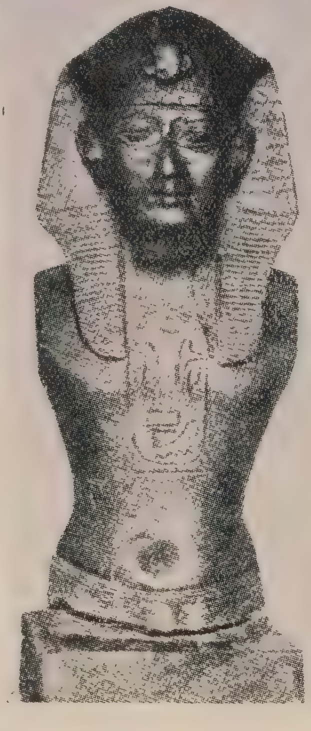
PAPERS PRESENTED TO BRANCHES

Lancashire Branch **Paper No. 777**

Essential Points in the Production of Non-ferrous Castings*

By W. BROWN† (Member)

If foundrymen turn their thoughts to that period of history when man melted his first metal and made his first casting, which is now generally acknowledged to have been copper, it would surely be with no small sense of pride, and humbleness, with which they link themselves to those pioneers of ancient days, and awaken to the fact that the art and craft of bronze founding must have been among the first of man's foundation-stones in the building of modern civilisation.



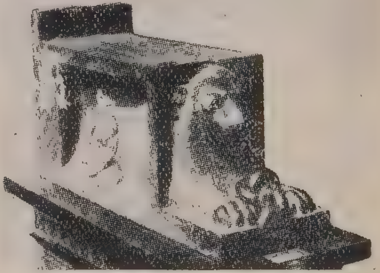


FIG. 1 (*Left*).—BRONZE STATUE OF KING PIUPI AND HIS SON (*Circa.* 2800 B.C.). FIG. 2 (*Centre*).—RAMESES IV (*Circa.* 1200 B.C.). FIG. 3 (*Top Right*).—BRONZE LION (*Circa.* 700 B.C.). FIG. 4.—UNFINISHED CASTING OF A BIRD.

Although so old as to be almost lost in antiquity, sufficient evidence has been found in various parts of the world to enable the methods by which man made his first castings to be visualised. Many of these early castings have been found in a fairly good state of preservation and have been set up in various museums and other places, and in looking at them foundrymen particularly can understand only too well the difficulties which must have been met with and overcome.

Early Egyptian Castings

Fig. 1 shows a pair of life-sized statues which now stand in the Cairo Museum. These two castings date back to the 6th Dynasty, roughly about 2,800 B.C., and are probably the oldest castings ever to have been found. They represent King Piupi and his son, and the museum catalogue gives the analysis of the metal as copper 98.2, nickel 1.06, iron 0.74 per cent. Although it is impossible to obtain a really close view of these statues, as they are kept in a sealed glass case, they are still very striking looking figures, with their eyes of inlaid black and white enamel. The statues were set up just as they were found, no attempt at cleaning being made. They are hollow and there is much divergence of opinion as to the manner of moulding, the most popular being that of the *cire perdue* or lost wax method. To the foundryman such a method does not commend itself, taking into account the size of the statues and the climate of the country. It is far more likely that the statues were made in several pieces from either wood or stone patterns and afterwards fastened together by riveting.

Fig. 2 shows the bronze statuette of Rameses IV (about 1200 B.C.). This is a very beautiful piece of work and, although there has obviously been some engraving done, the chisel marks can be seen quite plainly on the back of the statue; it shows that the art and craft of moulding had already developed very considerably. Another point of interest in the statuette is the rather intricate type of the mortise and tenon joint used to join the arms to the body.

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* The Author was awarded a Diploma for this Paper.

† Brassfoundry Manager, Mather & Platt, Limited.

Another beautiful piece of work is shown in Fig. 3. This casting can be dated at about 700 B.C., and again shows more progress having been made in the moulding methods. The lion is about 25 in. high, and is hollow, the only outlet for the core gases being a small hole at the back of the casting. The links of the chain must have presented a very pretty problem to the moulder.

One further example of the work of those early moulders is shown in Fig. 4, which shows an unfinished casting of the legs and feet of a bird. Here, undoubtedly, the lost wax method has been used, as there can be no other explanation of the design and shape of the "gates."

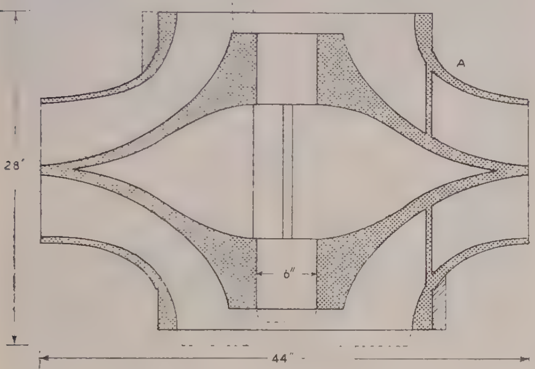

FIG. 5.—SECTION OF AN IMPELLER SHOWING POSITION OF CHILLS.

There are many other examples of early castings in the Cairo museums, and any foundryman who ever has the opportunity of visiting Egypt will find plenty of food for thought.

The Importance of Fundamentals

During the passage of time, many things connected with progress have changed out of all recognition from their earliest beginnings, but the fundamentals of bronze founding, and the purposes to which the castings are put, remain much the same to-day as they were thousands of years ago.

It is interesting to find in the Book of Exodus what is probably the first recorded order for bronze castings. (The word bronze is used instead of the usual biblical word brass, because it is extremely unlikely that brass was known in that part of the world, at that time.) Moses was commanded to "cast five sockets of bronze for the door hangings of the tabernacle."

Turning to the Book of Kings, there is nearly a whole chapter devoted to a description of the bronze castings used in the erection of the temple built by Soloman and of the man—Hiram of Tyre—who moulded and cast them. Hiram would very rarely have been called upon to make more than one off any job and therefore would give the essentials their full measure of thought and consideration on every mould he made, in much the same way that the "special" job is treated in foundries today.

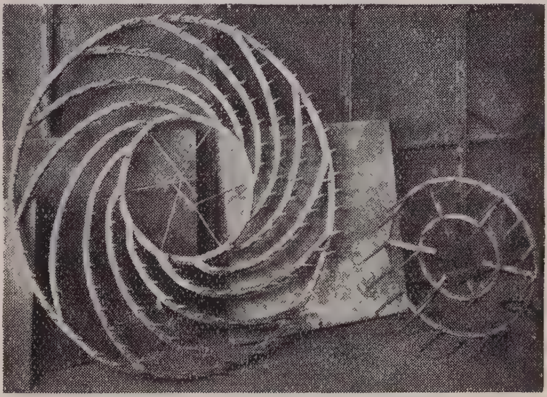

FIG. 6.—IMPELLER CORE GRIDS.

In most foundries there has been made, at some time or other, some one casting, which by reason of its size, weight or intricacy, or a combination of all three, has become a pride and an example to the particular foundry where it was made and as such is cited on all possible occasions and particularly during an "inquest."

If it were possible to take a record of all such castings it would probably be found that the percentage of wasters would be so small as to appear almost miraculous, but there is no miracle. The most likely explanation is that every one had his craftsmanship challenged and took very great care that there was nothing left to be desired as far as his part was concerned and at the same time he would be overlooking

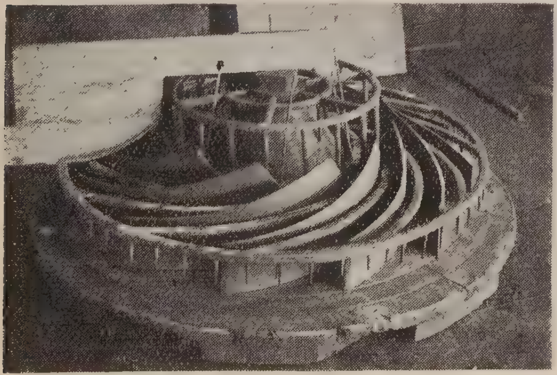

FIG. 7.—POSITION OF CORE GRIDS IN CORE BOX.

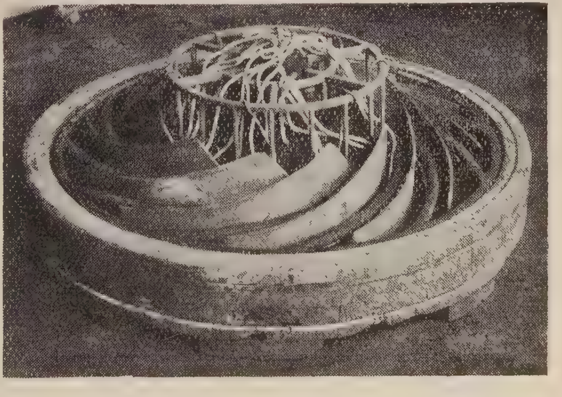

FIG. 8.—SHOWING GRIDS FASTENED TOGETHER, CORE HALF RAMMED UP AND METHOD OF VENTING.

other people's work also. In other words the essentials were given their full measure of thought and care.

If this job were to become a standard product, it would be fairly safe to predict that it would only be a question of time before trouble would begin to be experienced. Somebody would successfully "chance" something, and thus encouraged other "chances" would be taken resulting ultimately in a waster casting.

In the whole of the operations necessary to produce any single casting, there is nothing over which the founder has not absolute control. That being so, there should never be such a thing as a waster casting. This is an ideal, difficult of achievement in practice, but one which should never be lost sight of. There is a tendency to think that wasters are bound to happen and excuses of this nature are even used in explanation of the failure of a particular casting.

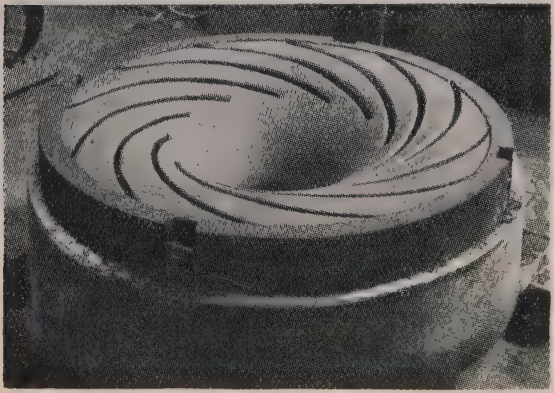

FIG. 9.—BOTTOM HALF CORE READY FOR STOVING.

The saying, often quoted in foundries, "that the man who never made a bad 'un never made a good 'un," is bad philosophy, particularly when, with an air of wisdom, it is dinned into the ears of foundry apprentices. At its best it does not help in the production of sound castings, and at its worst it leaves the foundry trade open to the suspicion that it is only by sheer good fortune that sound castings are ever made at all. If our essentials are sound, castings of quality will surely follow without the aid of any good fortune.

There is no order of priority in these essential points in the production of bronze castings. A properly constructed mould is useless unless backed up with properly melted metal cast at the right temperature, and *vice-versa.* In fact all the essentials are so bound up one with the other, that it is impossible to disassociate them, which explains in some measure the decision to illustrate this Paper with all the details of one casting only, rather than to give a miscellaneous collection of castings with little detail of any single one.

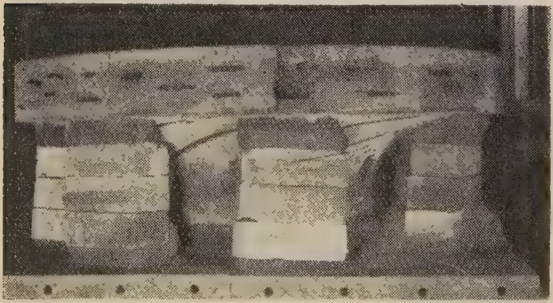

FIG. 11.—SHOWING BOTTOM HALF CORE DRIED WITH PACKING RING REMOVED AND THE METHOD OF REINFORCING SAND BACKING.

It may appear that much of the following will be very elementary, but it is well to remember that every job has very elementary beginnings, and it is the lack of care of those elementals or the easy familiarity with which they are treated which is responsible for most waster castings.

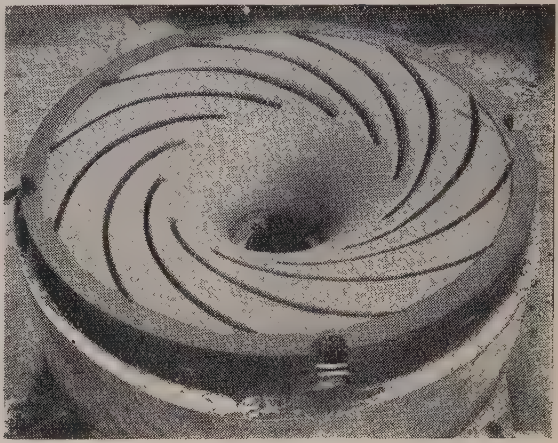

FIG. 10.—TOP HALF CORE.

A Bronze Impeller Casting

Fig. 5 shows the job chosen for consideration, a double entry bronze impeller. There were two main reasons for this choice, first, that the moulding is carried out by means of strickles, probably one of the earliest methods of producing a mould, and secondly, on account of the large amount of comparatively thin section, abruptly connected to much thicker section, which has to be run. In all, in round figures there is about 50 sq. ft. of $\frac{1}{2}$ in. section. The plan view is circular, and there are twelve vanes in each entry. Each vane is about 28 in. long, from the periphery to where it joins the neck. Only one vane is shown

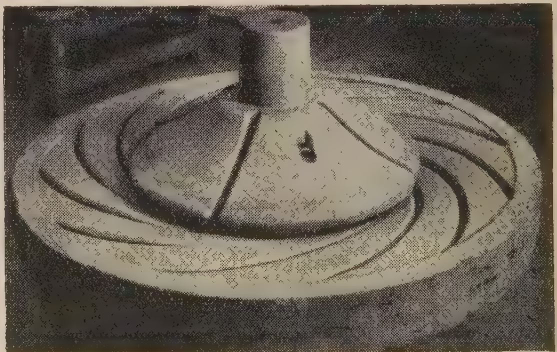

FIG. 12.—FIRST STAGE IN ASSEMBLY. THE CENTRE CORE IN POSITION, THE LIFTING HOOKS ARE ALSO SHOWN.

in Fig. 5 in order that the view may be clearer. Looking at the cross section, which is the only guide that the foundry has, this section being marked out on the strickle boards, attention is immediately focused on to several points which will require care and thought. For ease in making, the main core is made in two halves, split at the horizontal centre line. This means that these two half cores will need high dry strength to prevent sagging, a very little of which would be quite fatal.

The top half will need to be turned over and once in that position can be suspended only from the outer edge. Strong grids are therefore the first essentials. The centre core is somewhat similar, having a very small seating area compared with its overall diameter. The core is supported solely on its 6 in. dia., and obviously, surrounded by thin section metal, the slightest distortion or movement in the mould during pouring would mean failure. This core, too, requires a grid of some strength. Gas evolution will also be very great from these cores; therefore the sand, whilst necessarily strong, must also be free venting.

The thicker sections of the two necks are the next points requiring special attention, particularly where the inner vanes also join up. This occurs at twelve places equidistantly spaced round the diameter of the necks. To attempt to feed these spots by means of risers would be rather hazardous and so slight chilling will be the easiest, cheapest and most efficient method of dealing with this problem.

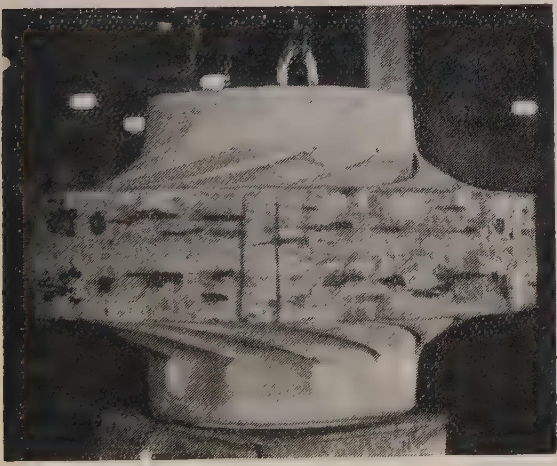

FIG. 13.—FINAL ASSEMBLY OF IMPELLER CORE SHOWING METHOD OF LIFTING.

Of the two thick sections of the shaft hubs which are supported by means of four ribs each 1 in. thick, the bottom one will be well cared for by hydrostatic pressure in conjunction with a supply of feeding metal down the four ribs. This metal will have to come from the upper hub which will therefore call for a supply of hot metal at that point. This determines the positioning of the gate and runner, that is on the upper hub. One other point to be noted from this cross section is that the metal having entered the vanes at the lower part of the mould the upward flow will be very slow, and it will be essential to pour quickly to obviate the danger of misruns or cold shuts. With this diagnosis the job can be proceeded with.

Coremaking

Fig. 6 shows the core irons for one half core, and the strength of the main iron, particularly the outer ring, from which all suspension will be made when the core is made, will be noted. The soft iron rods in the centre are cast into the main grid and are used to connect up with the smaller grid which is used in the neck. Fig. 7 shows the position of the grids more clearly although they have still to be adjusted. The soft iron rods can be seen projecting through the top grid ready to be bent over to fasten the two grids together. The outer ring of the core box has been removed in order to show the position of the grids more clearly. The strickle of course is to give top shape to the core after it has been rammed up. Note also the cast-on brods all helping to give strength to the core.

Fig. 8 shows the core partly rammed up, the top grid is now fastened down and the outer ring is in position. The point to note is the method used for the venting of the core. The chief advantage of wax taper is that it can be used quite freely without undermining the strength of the core, which would not be the case if coke breeze were used. In addition the tapers are very accommodating to the varying contours and curves.

After the core has been rammed up and strickled off a loose sheet iron ring deep enough to cover the core is placed on the box edge and rammed up with floor sand and a plate put over the top. The whole is then turned over and the core box removed. Fig. 9 shows the bottom half core finished off and partly blacked, ready for the stove. The packing ring just described can now be seen. The blacking of the vanes is a rather tedious business and a much better job can be made of it after the core has been dried. Failure adequately to paint the vanes would result in rough passages, difficult to clean and seriously impairing the efficiency of the finished impeller.

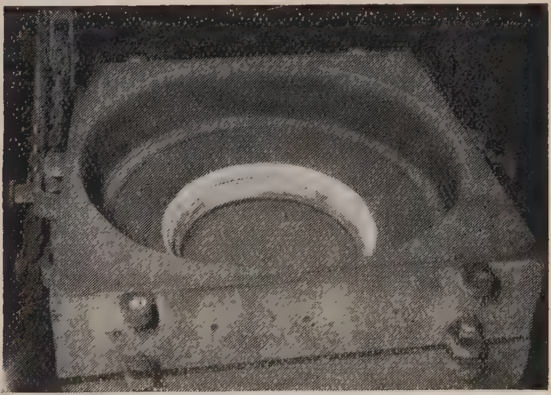

FIG. 14.—BOTTOM HALF OF LOAM MOULD SHOWING CHILLS.

Fig. 10 shows the top half core. The runner gate has been roughly cut and the grid, used for lifting purposes and turning over, is shown exposed. The wax vents can also be seen at the outside of the core.

The half core, after it has been thoroughly dried, is shown in Fig. 11. The wax vent has now melted away and the outlets can be clearly seen. It should be mentioned that all the gases from the two main cores are taken away at the periphery. Details of the packing of the core are also shown. As was stated earlier, the slightest distortion of either core would be disastrous both from the point of view of assembling and of metal thickness. Fig. 12 shows the bottom half core with the centre core in position ready to receive the top half. The ribs connecting the two shaft bosses can now be seen running through the centre core.

One could well ask why is not the core assembled in the mould, as the core would be greatly strengthened by sitting in its core prints. The answer is that the vanes in both halves must be in perfect alignment, a job much more easy to perform outside the mould.

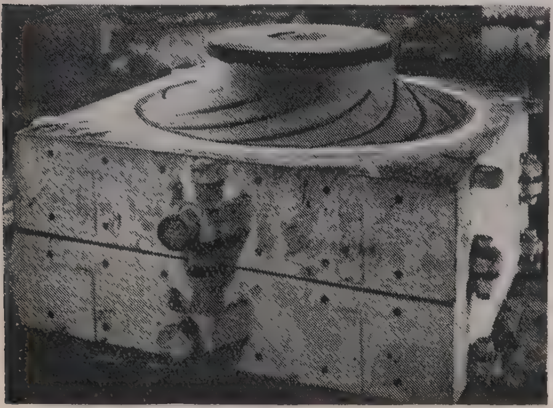

FIG. 15.—SHOWS THE CORE IN POSITION FOR THE BOTTOM HALF MOULD.

Fig. 13 shows the finished core. The method adopted for the lifting of the whole core is now seen. A lifting screw passes right through the centre core and is screwed into the bottom plate, provision for which has already been made in the mould.

Moulding

The moulding of this job is not difficult and needs little comment. Fig. 14 shows the drag ready for the core. Strickles are used instead of a full pattern, and the chills have been painted with french chalk merely to show them up in the photograph. Fig. 15 shows the core in position in the mould. The runner gate can be seen at the top of the core, together with the top of the centre core. A good touch at the core edge is very necessary to ensure that metal cannot find its way into the vents. It can be seen here that the joint between the two boxes is left slightly open, and there is also a gap between the box and the bottom plate.

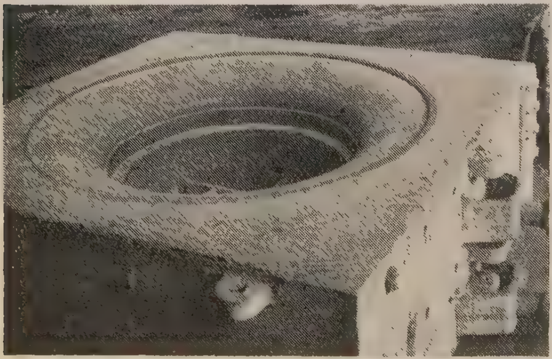

FIG. 16.—TOP HALF MOULD SHOWING THE CENTRE CUT AWAY AND LATER TO BE MADE UP. CHILLS ALSO SHOWING.

The top half, ready to complete the assembly, is seen in Fig. 16, which shows the cross bars used to "scotch" down the centre core.

Metal

Correctly melted metal, 2,700 lbs., is, of course, essential. It is melted in an open flame reverberatory furnace, and a slightly oxidising atmosphere is used when the temperature is being raised to its peak. When the impeller is being cast the first evolutions of mould and core gases take place at the middle joint, when the mould is half full. A pipe is led up to a position near the pouring basin to provide an exit for gases coming from the centre core. The continuance of gas flames for some considerable time after pouring has ceased shows clearly the large volume of gases which must be given free outlet.

Fig. 17 shows the impeller dressed ready for the machine shops, with the exception that the runner gate was left on for the purpose of this photograph. The whole make-up of the job is now clear, and the weight of it is just over 2,000 lbs.

In conclusion it should be emphasised that this job was not chosen for any special difficulty either in moulding or coremaking, but to illustrate some of the essentials for the successful production of a particular type of casting. The essentials are:—(1) A strong, well vented, true to shape core, and a perfect alignment of top and bottom halves; (2) a mould true to shape, well vented, either naturally or artificially, the core made up in such a manner that access to the vents by the molten metal is impossible; (3) the effective "scotching" down of the centre core, and (4) metal quickly poured and cast at the correct temperature.

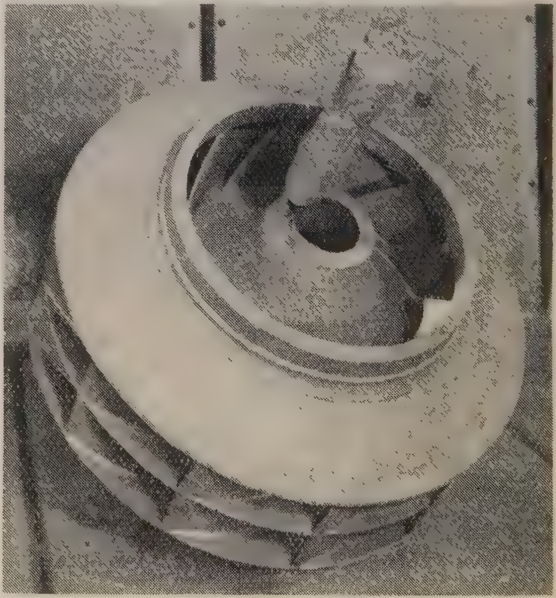

FIG. 17.—FINISHED IMPELLER CASTING SHOWNG METHOD OF RUNNING AND DESIGN OF GATE.

Acknowledgements

The author would like to pay tribute to his friend and colleague, Mr. E. J. Lambert, for his very excellent photographs, without which this Paper would have had very little interest. Acknowledgement is also made to Messrs. Charles Griffin & Company, Limited, for permission to reproduce Figs. 1 to 4 from Prof. Garland's "Ancient Egyptian Metallurgy."

Foundry Technique in Relation to Certain Pressure Castings*

By F. DUNLEAVY† (Member)

This Paper is simply a description of methods of making certain castings. The author does not claim that the practice is new or that it is the only way of producing these types of castings, but it is an account of the author's foundry practice, with a few selected examples showing some of his difficulties.

Small Grey-Iron Impellers

In the production of small, grey-iron impellers, the usual causes of rejection are misruns, drawn-in bore, blowholes on shroud, unequal thickness of top and bottom shrouds. The latter defect is more noticeable when the impellers are machined down to a smaller diameter. These troubles occur much more frequently in grey iron than non-ferrous alloys. The probable explanation is the fact that in pouring, temperatures are increased from around 1,150 deg. C. for non-ferrous alloys to around 1,300 deg. C. for grey iron, thereby causing a more rapid expansion of the core and greater volume of mould gases.

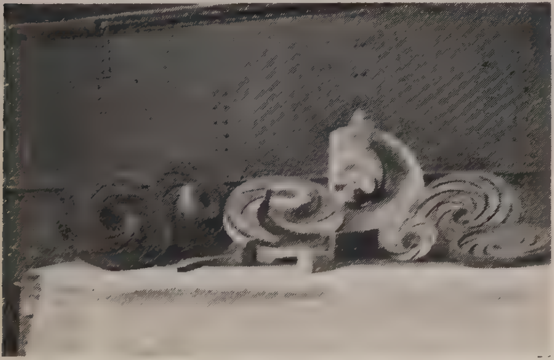

FIG. 1.—SMALL IMPELLER CORES.

Misruns.—Misruns are mainly dependent upon ingates in relation to section of casting, temperature of metal and metal composition. Consideration of these factors can do much to eliminate this trouble. To obtain correct temperature and composition for the thinner types of impeller, melting is carried out in an 18-in. diameter cupolette. The use of this small melting unit ensures the metal being free from contamination by other charges and solves the machining problem of the shroud tips occasionally being white.

Draws.—The iron used must be soft enough for the thin section, thus draws in the bores are due to the much greater thickness compared with shroud. To eliminate the draw the bores of these impellers are now chilled with either mild-steel or grey-iron chills in place of the straight centre core. When these castings are made in non-ferrous alloys, the centre boss is cast solid and run directly through this portion of the casting.

Blowholes.—Blowholes from a green-sand mould can usually be attributed to wet sand or sand rammed too hard, the inevitable result being that the mould gases tending to take the line of least resistance, which is upwards through the metal, cannot get away quickly enough, due to the quick cooling rate of the shroud. Facing sand with a low permeability will give similar results.

Blowholes from dry-sand moulds are due mainly to insufficient drying and a low permeability sand. The results are very similar to those in green-sand moulds. Blowholes from the core are caused mainly through the cores being improperly baked and incorrect venting. Venting of the smaller and thinner types of impellers is only effected by puncturing the skin of the core on the top of the print of the centre boss.

Small impeller cores such as are shown in Fig. 1 are made in a specially prepared sea sand with a linseed oil base and 6 per cent. moisture added by a standard measure. In the making of these small impeller cores, the sand is packed into the corebox with the fingers. Where necessary, wires are worked into the centre of the sand. The core is then again packed by the fingers to the top of the box and the centre boss swept out by means of a strickle worked from a centre spindle fixed into the corebox. If the corebox is made with the boss upwards, after the core has been made, a wooden frame which is slightly deeper than the centre boss is placed on to the corebox. This is rammed with wet sea sand and the whole assembly turned over on to a plate. Corebox and frame are drawn off and the core then stands upon a plate of wet sea sand, this being the only type of carrier used. When new boxes are being made or old ones being replaced, an attempt is made to make these cores with the bosses downwards to eliminate the wet sand packing and reduce the chances of distortion of the cores.

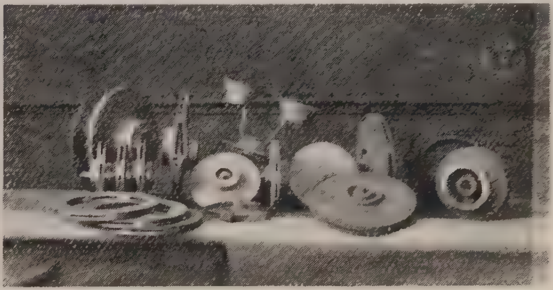

FIG. 2.—RANGE OF SMALL CAST-IRON IMPELLERS.

In the past it was suspected that blowholes were due to cores not being sufficiently dried, and to correct this each core was placed on to a brazier or open fire and burned slightly or until the bottom side of the core had turned to a dark colour, but this practice was only moderately successful. A thorough investigation revealed that the blowholes were mainly due to the core gases being obstructed in their exit from around the centre boss. Vents along the vanes were not so important as at first thought.

The present practice is to make sure of the baking and to break the skin of the core with a wire or sprig on the top of the boss on opposite sides from the runner and riser. A touch between the top box and top of core is essential to release the gases through the top box from the heaviest body of sand. Experience has proved this method to be successful in eliminating blowholes from the cores.

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* The Author was awarded a Diploma for this Paper.

† Foundry Manager, Worthington-Simpson, Limited.

Fig. 2 shows a group of several types of grey-iron impellers. On the left are three castings that have been machined down to a smaller diameter and the parted-off rings. When the rings were cut off, the impellers were found to be unserviceable, as the top shrouds were too thin owing to the cores having warped during pouring; very often the introduction of more ingates of smaller diameter allowing the metal to enter the mould over a larger area prevented this warping of the core. In extreme cases it was found necessary to use stronger flattened wire to achieve the same object.

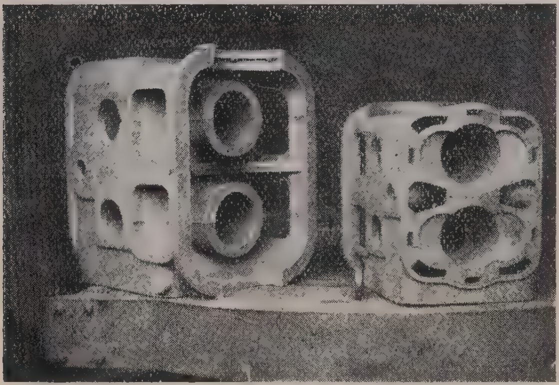


FIG. 3.—COMBINED AIR-COMPRESSOR CYLINDER AND CRANKCASE.

Fig. 2 also shows one method of overcoming the hard tips on the edge of the shroud. A thickened rim of metal is cast all round the outside edge and later removed during the machining operations. A typical final analysis for these castings is:—T.C, 3.3; Si. 2.6; Mn, 0.6; S, 0.10; and P, 1.0 per cent.

Combined Air Compressor Cylinder and Crankcase

Fig. 3 shows two sizes, 1,250 lbs. and 660 lbs. respectively, of a combined air compressor cylinder and crankcase. The design is identical in each case; only the dimensions vary. Inspection of these castings is particularly thorough, and slight defects in the bore, or on the outside around the water jacket, or failure on hydraulic test of 200 lbs. per sq. in., cause rejection. Due to the number of rejected castings, the original method of manufacture had to be altered.

Fig. 4 shows the former method of moulding and casting and illustrates a complete set of cores and the bottom half-box, tilted to show the inside of the mould, with the downgate on the right. The bottom inlet to the mould enters at the bottom flange and not on this joint face. Two top runners fit into the cylinder bores, and provision was made for them by cutting away part of the box ends. This box is two parted, rammed up by a Sandslinger, and dried in the stove. The box size is 5 ft. 10 in. by 4 ft. 6 in. by 2 ft. 3 in.

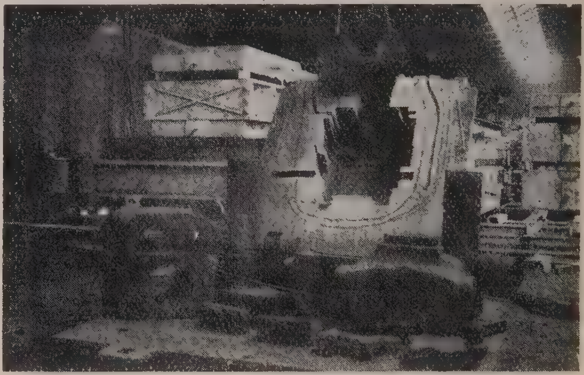


FIG. 4.—ILLUSTRATES THE ORIGINAL METHOD OF MAKING THE CASTING SHOWN IN FIG. 3.

Special care must be taken with the cores for these castings, and the assembling in the mould constitutes quite a problem. The centres of the cylinder bores must be accurate; also, the mould thickness around the jackets must be correct. Badly made or distorted cores will throw out the centres and cause endless trouble during the coring-up process.

Fig. 5 shows the completely cored mould ready for final closing. The vents at the top of the cylinder bores were made up with sand, in order to ensure that no metal enters, and led off through the side of the box when it is in position for casting. All the cores for these castings were made in sea sand with an oil binder, and great care was taken to make certain that the air had an easy exit to atmosphere. Jacket cores

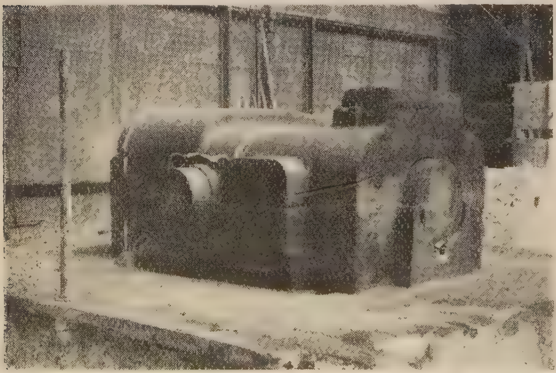


FIG. 5.—MOULD READY FOR CLOSING.

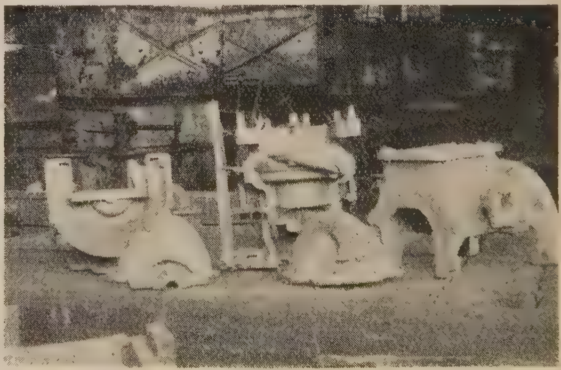


FIG. 6.—THREE SETS OF PUMP CASINGS.

were vented by breaking the skin at the prints in several places. When the mould was being closed, the top moulding box was set to marks and pins to ensure a correct register. The whole assembly was bolted up and turned on end to cast. A cushion of metal was assured before the two top runner plugs were lifted.

This practice was followed for a long time with varying success. The moulds were poured as hot as possible in order to keep the bores clean. The ladle was taken from under the spout, skimmed off, taken straight to the mould; even then a very small patch of sand was sometimes found in one bore sufficient to scrap the casting. Very often it appeared to be a very small patch of open metal, until the casting was broken up, when the sand theory was upheld. On investigation it was found that the fluid metal was scouring the top jacket core, which is shown in this view.

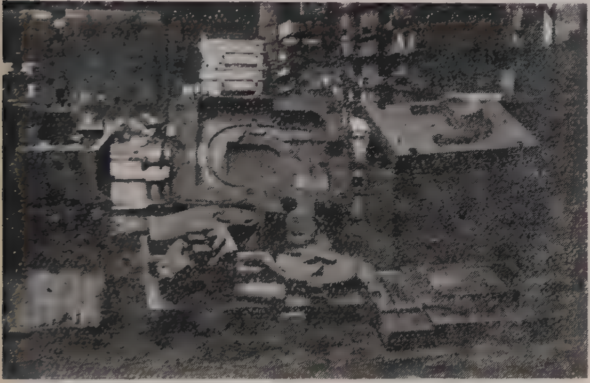


FIG. 7.—PRESENT METHOD OF MAKING PUMP CASINGS.

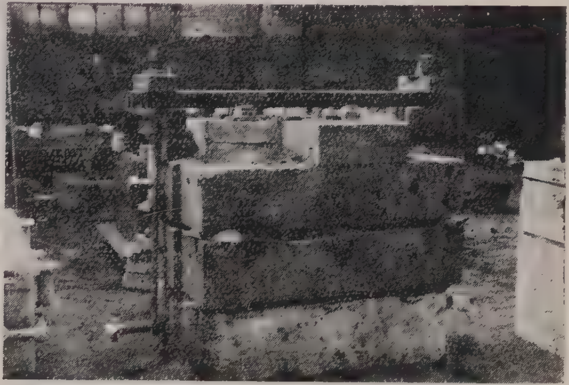


FIG. 8.—SHOWING THE MOULD READY FOR CASTING.

Compared with the old, the present method of casting is far more satisfactory. There has been a slight alteration in design, permitting the moulds to be cast in the same position as they are cored up, and changes in the method of running. The new design allowed two core prints on the jacket cores at the opposite end to the end core prints on the top face of the mould, thus easing the venting problem. The new method of running is as follows: The bottom moulding box is rammed with two ⅝-in. down runners set into position on a board, and the mould rammed to the top of this half pattern. Down the length of one side of the pattern, the mould is sleeked off and the inlet cores placed in correct position, one of these cores having two inlets and one in the other. The mould is now completely rammed, and the ⅝-in. down runner through the top box is connected to the two down runners to the bottom of the mould by a channel cut on the mould joint to break the flow of the metal.

The slight modification to the design ensured the release of the expanded core gases from the jacket core in a natural upwards direction, and the slower running of the metal by entering the mould over a larger area certainly appears to be the solution to a very large extent. A typical analysis of these castings is:—T.C, 3.2 to 3.3; Si, 1.4 to 1.6; Mn, 0.6 to 0.7; S, 0.11, and P, 0.4 per cent.

Pump Casings

Fig. 6 shows three sets of castings, from different angles, of rather intricate pump bodies. A close inspection of this view will convince one that the designs of these castings are such that they would be a very difficult problem to make in the normal way by having a separate pattern and coreboxes for the top and bottom half casings. Loose bosses and drawback cores would be too numerous, with the inevitable result of bosses out of position and the possibility of wrong cores being placed in the wrong prints, plus the numerous joint marks that are impossible to grind out satisfactorily.

Bearing these points in mind, the decision was

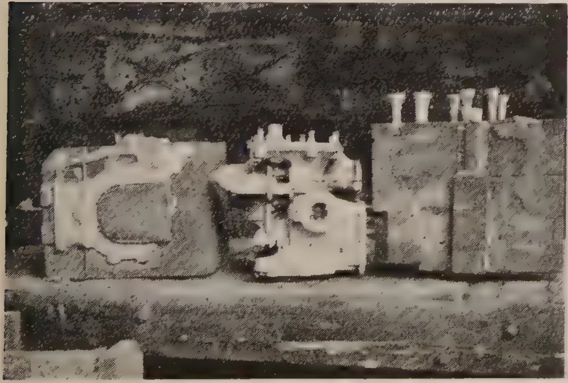


FIG. 9.—PUMP CASTINGS, BEFORE AND AFTER STRIPPING.

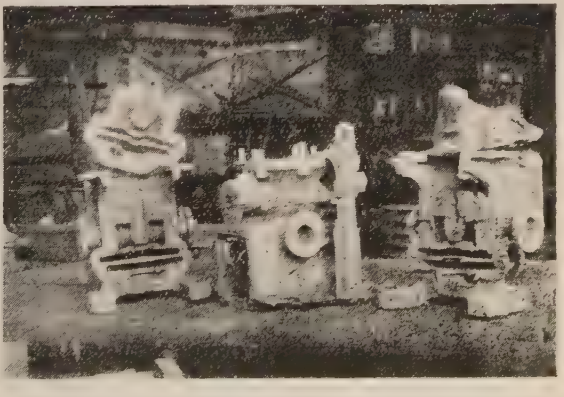


FIG. 10.—SHOWS A GROUP OF CASTINGS, ONE READY FOR MACHINING AND TWO UNFETTLED.

made to block out the whole job and make it in cores. A block pattern was made the full size of the job and rammed up by the usual foundry method and dried in the stove. The cores were fitted in to the mould, and it was found a rather difficult operation to set the cores correctly over the moulding box. This box was 3 ft. square, 3 ft. high, and as the metal thickness of the body is only $\frac{1}{4}$ in., if the core joints are not matched accurately the casting is a waster before it leaves the foundry.

Another fault with the block pattern principle was the question of taper in the coreboxes. All the boxes must be tapered the same way and fit correctly together, otherwise the resultant castings would be twisted out of truth. During the setting of these cores in the mould the difference between the pattern and coreboxes due to rapping became very noticeable on the core joints in the mould, and in some cases there was considerable clearance between the mould and the core.

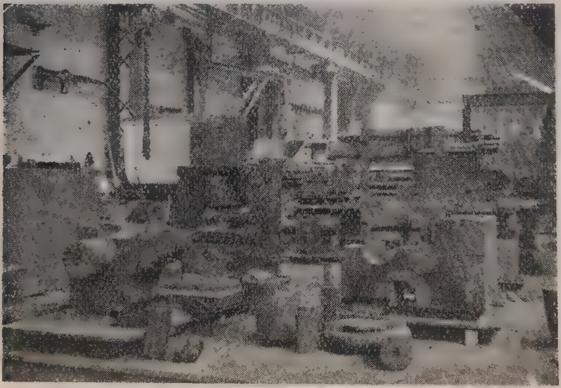


FIG. 11.—SHOWS A SET OF CORES FOR A COMPOSITE CASING.

The block pattern method was discarded in favour of the one shown in Fig. 7. The only piece of pattern now used is shown in the right-hand foreground. This is a forming piece for the bottom part of the assembly, and is the only piece of mould now used for this type of casting. The mould is shown tilted in the background. The three ingates are clearly shown on this mould portion, and have been fixed permanently on the pattern, and the inlets on the joints are all fixed into the coreboxes. All the cores are made in oil sand. Those forming the interior are in the centre of the view and the outside wall cores are on the right. The boxes for the outside wall are now held together during ramming with bolts and wing nuts and are taken apart instead of drawing the box off the core, thus avoiding taper, which is undesirable.

When the moulder receives these cores, they have already been matched up and marked by the coremaker to guide the moulder who works to those marks whilst building. It will be noted that the second core from the bottom has been split to enable the moulder to pass this core around the air vessel branch, which is an obstruction against a straight drop on, and to enable this particular spot to be checked for thickness.

When the whole set of cores is assembled, loose frames are placed on the bottom moulding box to surround the job. These frames are rammed up with floor sand to stop the cores from moving out of position. The whole assembly is bolted down to the bottom box; the top core is wedged to the straps to retard any upward strain and the runner box and risers are placed into position. Fig. 8 shows the completed job ready for casting.

Fig. 9 shows three castings, two in blocks before core removal, and the one in the centre having had the core removed and sand-blasted, but the top part of the casting still requires parting from the bottom. The block on the left is a view of the bottom of the casting showing the three inlets. The one on the right shows the method of making the down-runner. This is also made in oil sand and laid up to the outside core wall and directly over the inlets. The joints are made up with stiff loam. The down-runner is $2\frac{1}{4}$ in. wide and $1\frac{1}{4}$ in. deep. One advantage of this system is that the same method of running and feeding is used whether the material is either ferrous or non-ferrous. This practice is standard for this type of casting and is perfectly satisfactory in both metals.

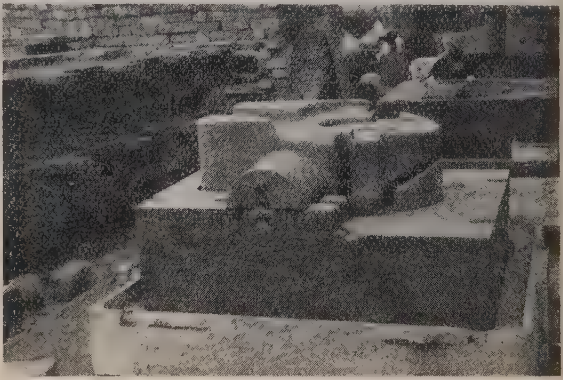


FIG. 12.—SHOWS THE CORE ASSEMBLY.

Fig. 10 shows three sets of the same castings from another angle. The total dressed weight is 324 lbs., the bottom half being 254 lbs. and the top half 70 lbs. The castings are subjected to 160 lbs. per sq. in. hydraulic pressure. Fig. 11 shows a set of cores for a similar type of grey iron combined top and bottom half casing. The standard runner cores are also to be seen in this view. The intricate design will be appreciated.

Fig. 12 shows the same set of cores partly assembled. The marked joints will be noticed. These marks facilitate the work of the moulder very much, although care must still be taken when building, par-

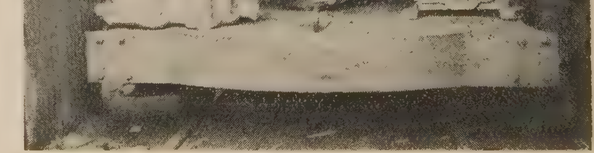


FIG. 13.—PATTERN AND CASTING OF A FURTHER TYPE OF PUMP CASING.

ticularly to the matching of the inside and outside cores for thickness. Fig. 13 shows another type of grey-iron pump casing made by the same method. The pattern is shown in the background. The casting in the centre has had the outside core removed, but still requires parting. The top half casting matches with the bottom half shown on the right.

High-Pressure Boiler Feed Pump

Fig. 14 shows the top and bottom half mould, complete with a set of cores for a bottom half casing for a boiler feed pump originally made as a steel casting. The metal thickness of this casting varies from 1¼ to 5½ in. This drastic variation of section must be taken care of, in view of the fact that neglect of this attention will cause endless trouble when the casting is subjected to hydraulic test of 1,000 lbs. per sq. in. The metal used is a high-duty cast iron giving 17 to 18 tons tensile. A typical analysis is as follows:—T.C, 3.1 to 3.2; Si, 1.1 to 1.3; Mn, 0.7 to 0.8; S, 0.10; and P, 0.3 per cent.

Two down-runners were used, 2 in. dia. each, and one inlet from each runner. These are shown in this view. All the cores for this type of pump are still made in loam in order to make absolutely sure that there is no fusion of metal and core. Any defect of this nature in the waterway would affect the efficiency of the pump and cause the casting to be rejected. The drawback cores for the top half of this mould are all tied back to make certain the correct thicknesses are maintained and that the cores are not moved out of position when the top part is turned over. The main cores in the bottom half mould are also tied through the mould.

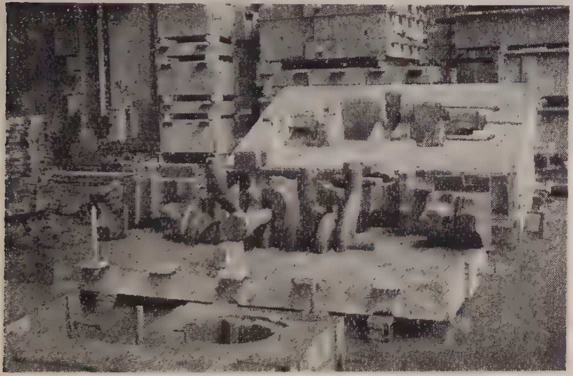


FIG. 14.—CORE AND MOULD FOR BOTTOM HALF OF HIGH-PRESSURE BOILER FEED PUMP.

Fig. 15 shows the pump body for this 6-stage pump and illustrates the position of the six impeller ways. The duties of a boiler feed pump of this type are very arduous. This particular one will pump water at the rate of 613 galls. per min. against 1,310-ft. head and works at almost 3,000 r.p.m.

Fig. 16 and Fig. 17 show the outside view of this casting from two different angles. The casting is 5 ft. 6 in. long, 3 ft. wide, 18 in. deep, and 40 chills were incorporated into the whole assembly, 21 on the mould, 19 in the core. A close inspection of this view will convince all that the chills were essential. Ten risers were used; the position of most of these can still be seen. The dressed weight of this casting was approximately one ton.

Gunmetal Evaporator Body

Although there is nothing very unusual about the moulding of the casting shown in Fig. 18, the method of running is of interest as the job is over 3 ft. deep and only $\frac{5}{16}$ in. metal thickness in the main. It was made in a three-parted moulding box and two joints were used to enable the mould to be run at the bottom as well as at the top. A later view shows that two down runners were used with a stepped joint. These were 2½ in. square; each one supplied three ingates 4 in. wide by ⅝ in. deep, plus two ingates the same size from each down runner on the top joint.

A dried runner box was used, the inside dimensions of which were 5 ft. 6 in. long by 1 ft. wide by 9 in. deep. This may appear to be excessively large, but it proved no more than adequate to maintain a head of metal in the runner box, which is necessary in order to exclude any foreign matter. The importance of cleanliness will be appreciated when it is remembered that the main body of the casting was only $\frac{5}{16}$ in. thick. Risers were used on the small top flanges and to avoid the possibility of air locks, a row of whistlers was arranged around the top of the casting and from external ribs. The centre of the top part moulding box was left open to enable the moulder to fill in with ashes, etc., after closing.

The complete set of cores was made in oil sand; the body core was made in halves with a grid in each half. There was a 3 in. clearance all round the grids with ample strawband used next to the grids and particularly in the rectangular box portion. This may perhaps be considered an unnecessary precaution, but the grids had to be broken through after casting to ensure that nothing was left undone that could assist the contraction.

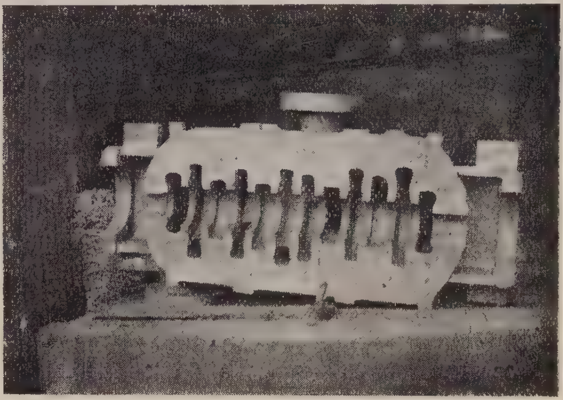
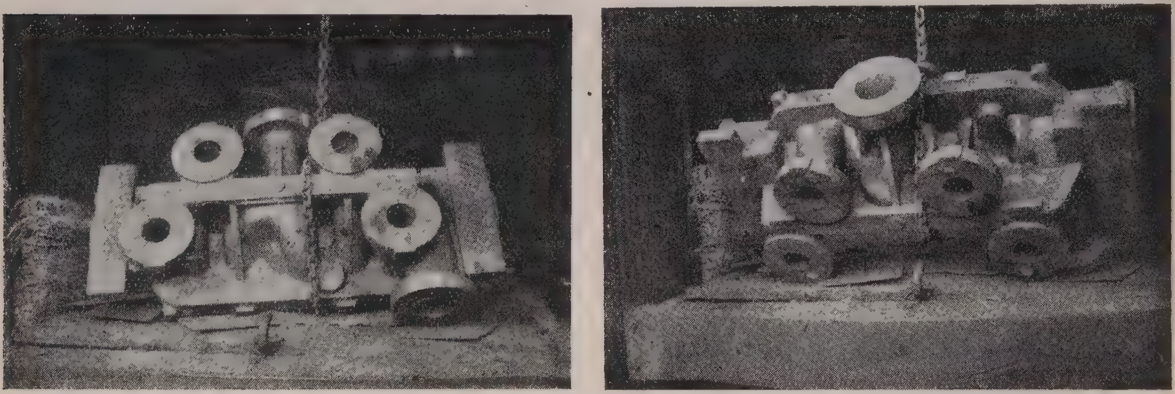


FIG. 15.—BOTTOM HALF OF BODY CASTING FOR 6-STAGE PUMP.

The centre of each half of the body core was made up of clinkers and rough ashes, leaving a minimum wall thickness of 6 in. of sand. One riser, 1¼ in. by ⅜ in., was cut on the centre joint of the half body core to be used as a large vent from the bottom face, thus eliminating any possibility of air locks. This vent or riser was actually connected to the main vents from each half core on the top joint. It might be thought that the metal would have found its way into the main vents, but this never did happen. The greatest length of metal to be found in this vent or riser was 8 in. Some eating in of the metal into the lower portion of the steam way core and the small cores was experienced in the earlier castings. This trouble was eliminated with the application of a proprietary dressing on these cores.

It will be appreciated that the coring-up of this mould demands the greatest degree of accuracy, for $\frac{5}{16}$ in. thickness of metal and a depth of over 3 ft.

do not leave a large margin for error. Thickness pieces were placed on the bottom of the mould and the main body core was centred on to these by means of laths. After final location of this core the steam box core was studded into position; the top moulding box was placed on and bolted to the middle part. The main cores were then packed to the box bars prior to being bolted to the top part. The mould was then split again at the bottom joint and metal thickness checked from that position to make certain that no movement of the main cores had taken place whilst the cores were being bolted to the top part.



FIGS. 16 (*left*) AND 17 (*right*).—VIEWS OF 6-STAGE PUMP CASTING AS FETTLED.

The mould was again blown out and was then ready for final closing.

It was considered necessary to ease the box portion of the core after casting. This was commenced 20 mins. after pouring, and the grids of the body core were also broken, thus making sure that there was nothing to restrict the contraction. Fig. 19 shows the casting looking from the bottom, and showing the inlets on the bottom joint. The metal used for these castings was gunmetal, and was tapped at 1,200 deg. C. minimum, the pouring temperature being 1,190 to 1,180 deg. C. The down runners were kept sealed with loamed plugs, and the runner box was kept full as previously explained. Fig. 20 shows the casting looking along the side. The stepped runner is clearly shown. The weight of dressed casting was 12 cwts.; the hydraulic test on the vapour box requires 40 lbs. per sq. in., and on the steam box 80 lbs. per sq. in. The rough dimensions of the casting are 3 ft. 3 in. high by 3 ft. 6 in. side to side, whilst the metal thickness at the vapour box is $\frac{5}{16}$ in. and at the steam box $\frac{3}{8}$ in.

Grey Iron Evaporator Body

Fig. 21 shows the early stages of a loam mould for a grey iron evaporator body casting, weighing nearly 6 tons, average section being $1\frac{1}{4}$ in. The first operation on this mould was a strickle to form the bottom print and flange. Then the strickle shown at the bottom of the centre spindle was used to sweep the radius from this flange to the outside wall of the body. The bottom of this casting is strengthened by a series of ribs. The foot or base was made in a corebox: two cores placed together making the full core, and all were made in loam. The outline of a cast-iron brick can be seen in this view. One is built into each half core and wedged tightly to each grid. Two iron bricks are built into the main body core to correspond with these positions, so that when the mould is being finally cored up the studs and the main branch print will hold the core in the correct position without the risk of crushing either the mould or core face.

The centre hole in the bottom face is 9 in. dia. and $7\frac{1}{2}$ in. deep. The metal thickness was formed by laying pieces of loam cake around the centre of the two bottom half cores, and the inside joints made up with stiff loam. All the ribs were filled up with

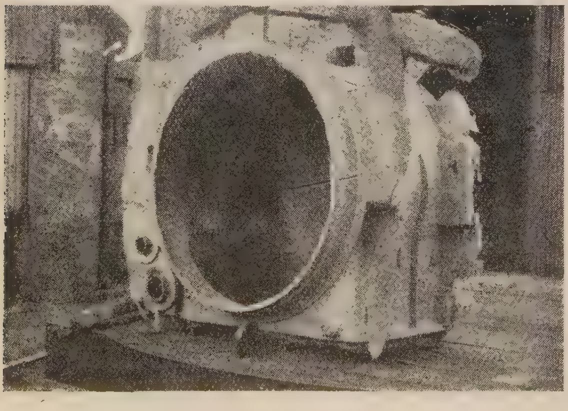


FIG. 18.—GUNMETAL EVAPORATOR BODY.

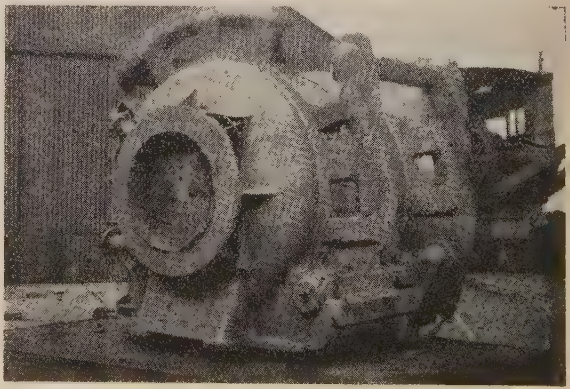


FIG. 19.—SHOWS THE GUNMETAL EVAPORATOR BODY WITH RUNNERS ATTACHED.

waste, and the frame which is in two sections is placed into position and checked for dimensional accuracy. Strong sand is used on the top of these half bottom cores to form the metal thickness. Here and there are laid pieces of wood to indicate this thickness at different points.

The same strickle which was used to form the radius from the bottom flange was raised up the centre spindle $1\frac{1}{4}$ in. and used again to sweep up the thickened bottom face, which was rammed fairly hard. The joint was assured by laying pieces of damp paper over the face. The building of the core was the next step towards the casting, and the first operation was making a grid for the centre hole in the bottom face. This was built up with loam cake and the grid wired firmly to the main grid. This main grid was kept well away from the mould face. Approximately every 6 in. or 7 in. around the outside ring were cast pieces of $\frac{1}{4}$ in. wrought iron wire about 8 in. long. These were bent to conform to the shape of the base of the mould, and wired again in two heights all around the circumference. This operation was to keep the cast in wire rigid enough to hold the coating of loam, strawband, ashes, etc., but not too rigid to retard the solid contraction of the casting. These extra precautions were taken because this portion of the core could not be eased after casting.

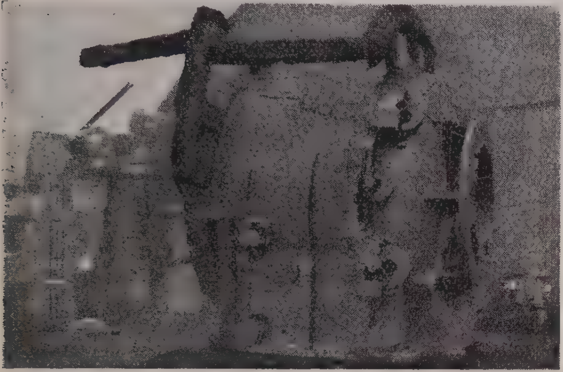


FIG. 20.—SIDE VIEW OF THE CASTING SHOWN IN FIG. 19.

The bottom lifting plate, which was approximately 6 in. less in diameter than the core, was then bedded on to a coating of loam on the bottom grid, which was bolted to the bottom lifting plate in four places. This plate was cast with three staples $1\frac{1}{2}$ in. dia., 15 in. long and six 3-in. square holes. Four of the square holes were used for the bolts between grid and plate and were left open. That is to say, all six holes were used to lead off the air from the bottom face, and where possible through the main branch to atmosphere. The rest of the air was carried through the brickwork to the top of the core. The centre of each course of bricks was rammed up with ashes that had passed through a $\frac{1}{4}$-in. riddle.

This view also shows the short strickle used to sweep up the core from the top rib to the top of the core inside the head. The long strickle was used for the back part of this core. The two down-runner pegs can also be seen on this photograph. They are $2\frac{1}{4}$ in. dia., one ingate led from each down-runner being 3 in. wide and $\frac{3}{4}$ in. deep.

Fig. 22 shows the core almost completed. This core, commenced on a coating of loam on the lifting plate, was built with an 18-in. wall, or double brick, for two or three courses, to take the strain of the metal during casting. From this point to approximately 3 ft. from the base the wall was $13\frac{1}{2}$ in., or one brick and a half thick, the rest being a 9-in. wall, or single brick.

Three further grids were built into this core approximately every 2 ft., and loam cake or brick was built into the whole depth of the core in the two sides and back, opposite to the main branch, to facilitate the contraction. The top and bottom core grids were bolted together in three places around the inside of the core in order to make the whole assembly rigid. These bolts were not tightened up until the core was dry. The mould was the next operation. All the pockets between the ribs were filled up with stiff loam to the metal thickness of the ribs of $1\frac{1}{4}$-in. section. The bottom portion of the mould was built into a part of a moulding box in order to save tackle and enable the use of existing binders. The vents can be seen through the sides of the box, strawband being led from near the mould face to atmosphere. At the far side of the mould, opposite to the branch, the ribs continue horizontally all the way round, thus connecting the two pieces of frame. The metal thickness of this part of the mould is made by wooden laths laid up to the core. The ribs are held into position in each length by three pieces of wood, $\frac{5}{8}$ in.

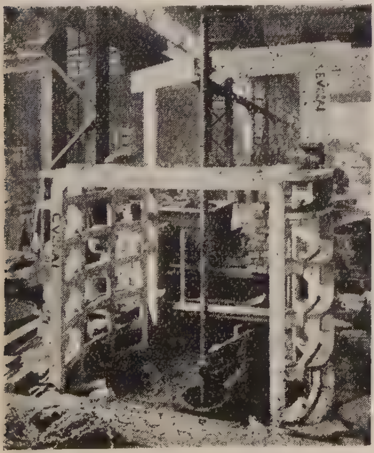


FIG. 21.—LOWER MOULD FOR GREY-IRON EVAPORATOR BODY.

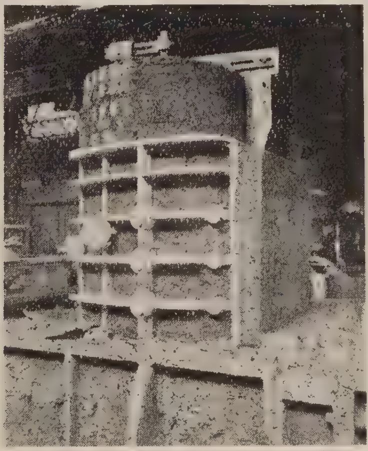


FIG. 22.—CORE FOR CAST-IRON EVAPORATOR BODY.

FIG. 23.—CASTING BEING MACHINED.

by $\frac{5}{8}$ in., which are removed after the core has been lifted out and the space made up with stiff loam.

The next step was the mould joint. This was made up to the top of the rib just showing over the box edge and leaving on the box approximately 1 in. of loam, which was levelled off and allowed to stiffen, thus making the first mould joint. The main reason for making a joint here was in case there was any difficulty in removing the frame, but this fear was premature, and the joint was never used. When this loam had stiffened another layer of loam was laid on, and the first lifting binder was clay washed on the underneath side and set on to the loam. The building started from here with a few small grids here and there in the pockets. All the bosses were loosened as the building proceeded. Another binder was placed around the middle and one on the top rib where another joint was made. A further lifting and one top binder was used for the straight top piece and the last joint made. A strickle board, $10\frac{3}{4}$ in. deep, 6 in. wide, was used to form the 9-in. head, thus leaving a $1\frac{3}{4}$-in. thick flange.

A grid was made to bolt to the top plate, which was swept up with loam. Two top runners, 3 in. by $\frac{3}{4}$ in. each, were made through this top plate for emergency purposes in case the mould did not fill rapidly enough, but it was not found to be necessary. When the building was completed, and before stripping for the stove, the building bars were placed through the slots in the binders and wedged in with iron wedges. The space between the bars and bricks was filled in with stiff loam. This was to offset the strain on the mould during casting and to take full advantage of the strength of the binders.

When the mould was ready for stripping, the loam joints were marked in order to enable the mould joints to be put back in their correct position. The straight piece to the top of the rib on the outside was lifted off first. This was followed by taking the piece of frame away that covers the branch print. Next the core was lifted out, mended up and dried in the stove. The frame was taken apart, the mould mended up and dried with a muffle drier. After drying, the surfaces of both mould and core were roughened up and blacked whilst the parts were still warm.

The finished casting shown in Fig. 23 was eased through the top of the job through the main branch to the bottom core lifting plate, also all the way down the opposite side immediately after pouring, to allow the casting to contract normally. The oblong facing shown under the head was let into the mould wall. All the solid bosses were filled with studs and pipe nails to accelerate the solidification. The casting was tested to 220 lbs. per sq. in. hydraulic pressure at the vapour way and 480 lbs. per sq. in. at the steam way. These pressures are approximately double the working pressures.

The height of the casting with head was 7 ft. 5 in.; the outside diameter, 5 ft. $8\frac{1}{2}$ in.; the inside diameter, 5 ft. 6 in., and the dimensions of the head 9 in. by 6 in. The total weight of casting and head was 5 tons 12 cwts., that of the head 12 cwts.

The analysis of the iron for this type of casting is:—T.C, 3.2 to 3.3; Si, 1.7 to 1.9; Mn, 0.6 to 0.7: S, 0.11, and P, 0.5 per cent. Fig. 23 shows the casting on the Bullard machine in process of having the head machined off.

Finally the author wishes to thank the management of Worthington-Simpson, Limited, for permission to give this Paper and for the use of the photographs.

DISCUSSION

MR. R. S. TURNER said that the type of castings described by Mr. Dunleavy was certainly very difficult to produce. Every credit was due to him for having mastered the problems which had to be solved. The castings appeared to be better if they were run fast, and the manganese content was stated to be approximately 0.7 per cent. in the cylinder and crankcase illustrated. In his (the speaker's) experience, in order to avoid dross on castings, the manganese content could be increased to 1 per cent. and the casting would be improved. He understood Mr. Dunleavy to say that he had ten 2-in. risers on the boiler feed pump casing. Were they for the purpose of feeding the casting, or merely as outlets to avoid air locks?

MR. DUNLEAVY, in responding, wished it to be understood that the work described in the Paper had been done throughout entirely with the full co-operation of the whole of the staff of the foundry, and was not the result of mere individual effort alone. Whenever trouble was experienced, the fact was made known generally and it was usually the case that someone could give the clue to the cause. Advice from any person was of course invaluable. Periodical meetings were held in the foundry for the purpose of discussing and endeavouring to arrive at a solution of difficult problems. The foundry did not have any more scrap than anyone else, although the scrap percentages were still too high, but its personnel did try to be honest and frank, admitting the existence of a difficulty whenever they were confronted with one.

He had not tried the 1 per cent. manganese referred to by Mr. Turner, and 0.7 per cent. was about the maximum. The ten risers need not be considered too much as feeders except on the top rib. The point was that there was some really fluid metal coming through the risers. There had been difficulty through the varying sections and an attempt was made to equalise the rate of cooling. A proprietory dressing was used on the bottom part of the mould in order to stop scouring, and it was desired that the metal should run fluidly into it through the risers. The risers on the rib were very effective, but on the flange their use was questionable.

MR. E. LONGDEN said a point for consideration was how much the foundry organisation was effectively and wisely controlled, because difficulties were bound to occur from time to time. For instance, there was often less scrap from a machine-made mould, because a more or less foolproof method of casting could be adopted. The size of the downgate could be determined in relation to the ingate, as well as the volume of the feeders on the job, etc.; nevertheless difficulties would be experienced. Even then there was probably less scrap than in the case of jobbing moulding. It was desirable that a record should be kept of the method of core-making and the moulding of important castings, and that the patterns should be marked as to the position of ingates, feeders, etc. The class of work described in the Paper involved real craftsmanship, and men had to be trained to do it. There had been very little said regarding the metallurgical point of view.

Running an Evaporator Body

A point which occurred to him was with regard to the running of the gunmetal evaporator body. Dealing with the multiple series of runners on this particular casting, it was noticeable that there was one single runner from which two separate ingates issued at two different joints. Was this correct practice? If so, why was it not better for the main downgate leading to the first joint to drop down to the second one rather than step it, and for the main first downgate to be smaller than the second one, so that there was no danger of metal flowing over into the second series of ingates on the top joint? One might get along with this practice for a very long time, but the moulder may have been taught to use a certain area of downgate and then find he is using $\frac{1}{4}$ in. less in diameter, or width, or both, and trouble results. Possibly, if the main downgate was smaller than the one falling through to the bottom joint, there would be no danger of metal actually flowing into the top gates before it should. Dealing with the occurrence of patches of trouble, this very often arose owing to the filthy condition of the runner-gate system.

MR. DUNLEAVY said that a job was not given to a man in the foundry with instructions to run one- or six-off or 12-off. His instructions were how to make it, and it was seen that those instructions were carried out. It was often the case that a job was given out, and the first two moulds or sets of cores were made, and then something went wrong. Perhaps an instruction was not carried out. He did not wish for a moment to be thought to be congratulating himself upon a small scrap percentage. The scrap percentages were still too high, but an attempt was made to face troubles frankly and fearlessly.

Multiple Pump Castings

In the multiple pumps described, the down-runners and ingates were made as foolproof as possible. That was because the human element simply failed, on repetition, to reproduce the same size of down-runners, ingates and risers. He thought he had shown in the illustration of multiple casings that there was no possibility of any filthy patches occurring through blacking, owing to the rigid system of checking instituted. A block was made in order to form the runner box, and the size of the box was standardised and the possibility of error thereby eliminated. Actually, after the early teething troubles with this job being overcome, a large number of castings were made before there was any trouble, so that personal experience of troubles with these castings, apart from material, showed they were mainly due to wear and tear of equipment. The main point to be observed was, if there were any trouble occurring, to ascertain its cause, otherwise the procedure was very much like running round and round in a circle. If the cause were ascertained, then a remedy could always be applied.

Evaporator Castings

The difficulty with the runners on the gunmetal evaporator body was that all the time the metal was going through the mould there was a chilling effect from the core and from the mould. It was not a job which could be cored up in an hour or so. There were a number of jib cranes in that particular section of the foundry, but even then there was much setting done to make sure everything was correct. A casting of this description which was $\frac{1}{8}$ in. out of truth was scrapped without the slightest hesitation. The metal was required to be in the mould as quickly as possible, in order to ensure there was no short run. It was considered that, as long as a head of metal could be maintained in the box, and all the dross was at the top of the runner box, the casting would be quite clean.

Impeller Cores

MR. A. SUTCLIFFE referred to an illustration of an impeller core for pump castings in non-ferrous or cast iron, which was approximately 18 in. dia. He stated that it was very easy to cradle such cores, or any shape of core, provided they could be stripped from the corebox. All that was necessary was a square or a round frame fitted with damped black sand, put through a sieve or quarter-inch riddle. Did Mr. Dunleavy use damped sea sand?

MR. DUNLEAVY replied in the affirmative.

MR. SUTCLIFFE said that in that case some of the oil would be absorbed in the wet sea sand used for the cradling of such a core. Was the oil sand milled?

MR. DUNLEAVY answered that it was mixed but not milled. It was mixed in the mixer, and the proportion of core oil was 28 sea sand to 1 of oil.

MR. SUTCLIFFE remarked he used a formula for core oil up to 80 to 1 for such cores, in a thin oil-sand mixing.

MR. SUTCLIFFE then referred to the method of running the gunmetal evaporator body, and then drew a diagrammatic sketch on the blackboard, which showed that any metal running into the mould from the top inlet runners and staying on top of some cores in the mould, would be set when the metal began to rise in the mould from the bottom inlets.

Design and Method

MR. DUNLEAVY, referring to the down-runners on the gunmetal evaporator body, said that Mr. Sutcliffe had evidently missed the point; two down-runners were used, but one had been broken off from the top joint. Usually evaporator bodies were made with a hole through the opposite end to the large print. In this case it was a blank end, and that was the difficulty. Another danger was scouring. This was overcome by arranging a piece of loam cake at the bottom of each down-runner. The other point was that to step the down-runners the flow of the metal was broken; unless this flow was broken there was a tendency to scour. The metal was proceeding at great speed. There were two down-runners on the job; one on each side. It was a matter of lifting the plugs as quickly as possible. It was essential to get the metal in quickly, because of the chilling action going on all the while the metal was going through the mould.

When this job is being cast the large runner box is filled. Then both loamed plugs are lifted together, so that there is the dross from ladle, etc., still on top of the metal remaining in the runner box after the mould is filled, so that there is no possibility of dross entering the mould. The runners and ingates sketched by Mr. Sutcliffe may be satisfactory in an ordinary mould, but evidently what he has overlooked is that this casting in gunmetal is 3 ft. by 3 ft. 6 in. by 3 ft. deep, the metal thickness being $\frac{5}{16}$ in. The whole aim was that the casting should pass the hydraulic test satisfactorily. Perhaps the main point was that these castings were subjected to hydraulic pressure tests. The method of running suggested by Mr. Sutcliffe would not be satisfactory.

He thought the statement that metal would enter the top inlets before entering the bottom inlets did not appear to matter to a very great extent, even if it were true, because with two $2\frac{1}{2}$ sq. in. down-runners the metal filled the mould too rapidly to have any injurious effect.

Oil-Sand Proportions

MR. J. MASTERS, SENR., understood Mr. Sutcliffe's question about oil content to refer to impeller cores. Mr. Dunleavy gave a ratio of 28 to 1, which, in his opinion, was a waste of oil. It should be quite safe to work with a mixture of 80 to 1 with a straight linseed oil or one of a similar character provided the mixing was done properly by weight. It was essential to indicate whether to mix by weight or by volume, because specific gravities were quite different. By reducing the oil content the drying time was reduced, and there was less tendency to distortion. In the case of an underdraw core there would be such a vast volume of gas that holes would occur. Having ascertained from the lecturer that the moisture content in the mould facing sand was 6.5 to 7 per cent., the speaker insisted that this was courting trouble. One firm had cast 400 of that particular type of casting, but the moisture content never exceeded 4 per cent., while the new sand content in the facing sand was less than 20 per cent. Seeing that such a large quantity of impeller castings was made, was it not found that the use of sea sand was detrimental to the cores. There seemed to be a waste of sea sand. Some firms packed the cores with wet sea sand, but later reused the sand to make cores. Referring to the gunmetal evaporator body, he would certainly advise that all down-runners for castings of this description should be blacked. He noticed from the slides that it looked as though the metal had eaten in.

Loam Brick Walls

The lecturer had stated that in the case of the loam job he had built a double wall. Was it an 18-in. wall?

MR. DUNLEAVY said there were too or three courses on the lifting plate with double brick; a brick and a half to half way up, and then single bricking to the top.

MR. MASTERS said he had often made pans which had to be turned over with a 9-in. wall, and the casting weighed 15 tons. A circular wall could be built. What was running through his mind was the thought of the tremendous amount of easing time necessary, and what a big job there was for the men doing the easing. A 9-in. circular wall would never burst inwards. He had never seen one burst, and he had seen thousands of tons cast.

Evaporator Body Core Assembly

Mention had been made concerning the assembly of the cores in the evaporator moulds, and a doubt expressed as to their action in chilling the metal. Would it not be advisable in a case where the casting was of such a character and of such an expense to assemble it at the mould, do all that was necessary, and then put it back in the stove, and heat it up for a couple of hours? This would reduce the liability to chilling, and any moisture that might be used in the making up of the cores would have a chance of being driven out. This plan would seem to make for a much safer job.

MR. DUNLEAVY said in answer to the first question, that the ratio of dry sea sand to proprietary core oil was 28 to 1 by weight. He had emphasised in the Paper that these methods were not necessarily the only ones, neither did he claim them to be new. He had described existing practice, and he claimed it was sound practice, as proved by the results. He would not attempt to cast these very thin impellers with green sand. These moulds were dried, even with a cupolette iron, the tendency would be that the impeller tips would be hard to machine. The small ones were dried, as the metal section was only about $\frac{1}{8}$ in.

Mr. Dunleavy stated that even with a moisture content suggested by Mr. Masters of 4 per cent., castings of this type would still be hard on the shroud tips. One point that was evidently overlooked by Mr. Masters was the analysis of the materials used. A firm cannot carry irons or materials to suit every type of casting, and would suggest that in the production of castings that are subjected to pressure tests, it was better to confine the final compositions to minimum and maximum limits, and to adjust the foundry practice to suit.

Impeller Defects

He had experienced trouble with impellers, but the general trouble seemed to be blowing on the shroud. The blowing was referred to in the Paper, and was mainly due to the amount of trapped gases around the centre boss. The solution to this problem was also given; *id est* the inspector condemned them before they left the foundry floor. The answer to the question respecting linseed oil and the expensive core, seemed to be that wartime was the wrong time for making promiscuous experiments. The foundry management found that all their time was filled up in coping with their commitments and their everyday foundry problems, also that it was far better to trust the devil they knew than the one they did not, until one could get down, if required, to the question of cost, etc. Wet sea sand had been referred to. The point was that metal formers were not used for the impeller cores. There was no room space to stock all the metal formers that would be required. The methods suggested in the Paper are everyday practice on a type of casting, which was after all their bread and butter.

MR. MASTERS was referring to the instance with peculiar shaped sweeps on the vanes. It would cost more to add sand half a dozen times than to make a cradle.

MR. DUNLEAVY, in reply, stated that these types of impellers were made in segments. The sweep of the vanes was always varying, on account of the different customers' requirements. This type of core is usually packed with black sand, but the general practice is to use wet sea sand. He again referred to the 18-in. wall, and added that there would only be a 9-in. wall even with a brick and a half, owing to the thickness of the interior facings, etc. The photographs were not complete for the purpose of showing the inside of the evaporator body, but actually a double brick was essential initially in order to provide an adequate foundation. This part of the wall was only about 8 or 9 in. high.

Dealing with the assembly of the cores in the gunmetal evaporator body and the chilling effect of the moisture from the joint of the cores, the body core was jointed and dried before it was placed in the mould, so there was no chilling from that joint, but there was a serious chilling area over the mould and the core, although both mould and cores were warm when coring up commenced.

Core Reinforcement

MR. H. HAYNES was interested in the loam casting. Good results could be obtained by this practice, but the moulders must be skilled. He thought Mr. Dunleavy must possess some knack of sweeping to strike a core so accurately from a 2-in. spindle without any shaft or gauge or anything else to work in at the top as well as the bottom. Had Mr. Dunleavy tried easing bars or iron wedges in these cores?

MR. DUNLEAVY said his firm had some exceptionally good moulders for the type of work described. All the work done was the result of the team spirit; there was no question of the waving of a magic wand. The bulk of the work on this core and mould was formed by a split frame. The only portions swept up were the print and bottom flange, the back portion of the casting and the head. The use of the iron wedge referred to was quite common practice, but some of the castings were so shaped that it was difficult to use easing bars. They were let in, in sections. The strain was outwards on the mould, rather than inwards, but the grids and strengthening post prevented any deleterious action.

Replying to Mr. E. Jackson, MR. DUNLEAVY said that they did not make impeller castings in manganese bronze. His company made impellers in grey and alloy irons, Monel and most of the copper-base alloys. Some of these castings would be a difficult proposition in manganese bronze.

Radiography as an Aid to Foundry Technique*

By W. GLADWELL (Associate Member)

In any gathering of foundrymen discussing the problems involved in making sound castings, one remark is almost invariably heard—"If only we could see everything that happens inside a mould during the pouring and solidification of the metal, the making of sound castings would be merely a routine business." Until it is possible to see inside a closed mould, such information will not be forthcoming. E. M. Currie's film, shown at the London Branch, went a long way towards providing it, but when part of the top half of the mould has to be removed, the question will still remain: "Does a fully closed mould behave in the same manner?" Until this information is available in full, an efficient substitute can be found in seeing inside the finished casting.

In order to achieve this, castings can be cut through at points where cavities are expected. There are several difficulties in this method, the most important being consequent on the fact that in a modern foundry making high duty castings, the position of gates and risers and the pouring temperature are no longer left to the individual moulder. These are, however, settled by the foundry foreman, who, if he has the casting cut up, will have it cut where he expected difficulties, having already taken precautions against them. Again, in non-ferrous metals, fine gas porosity may be completely obscured on the cut face by the action of the saw teeth. The specimen will then require polishing, and may need etching if this trouble is to be detected. On high-grade loose pattern work, an important consideration is that, if the initial moulding technique is proved correct, a casting in small pieces is one casting less to sell.

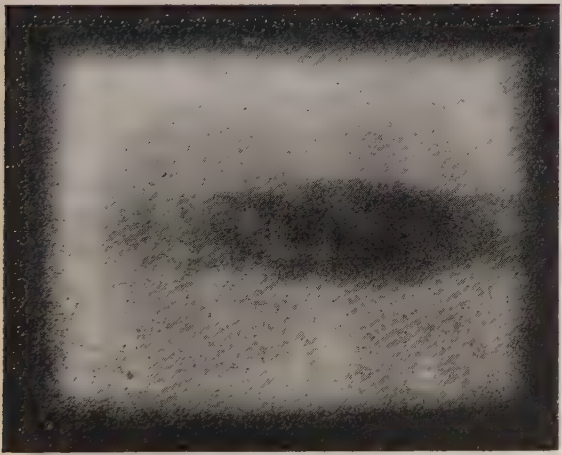


Fig. 1.—Radiograph of a Block of Copper containing a Large Shrinkage Cavity, to illustrate Photographic Contrast obtained.

On the other hand, non-destructive testing by radiography shows where the faults, if any, really are—sometimes a quite surprising feature—and at the same time leaves the casting intact.

It is not necessary for the purpose of this Paper to delve deeply into the technique of radiography, this being the affair of the radiographer, since foundrymen are more concerned with the information to be gained from the radiograph than the method of obtaining it. However, for the sake of clarity, before discussing the probable value of radiography to the foundry, it has been considered necessary to give the following description of the method of obtaining a radiograph, and a comparison of the merits and limitations of the methods of radiography. For anyone wishing to go more thoroughly into the subject, much literature is available, two notable examples being "Engineering Radiography," by V. E. Pullin, published by G. Bell & Sons (London), Limited, 1934, and "Industrial Radiography," by St. John and Isenburger, published by John Wiley & Sons, New York, 1934.

Fig. 2.—Showing a Step Block Radiographed by Gamma Rays.

Technique of Radiography

Radiography is not new to the foundry trade, and in fact radiographic examination of metallic articles was accomplished about 1900, and by 1930 it was well established as a method of testing in the light alloy field. Its more universal application was, however, probably hindered by the fact that whereas the short exposure times allowable before overheating, and the comparatively low voltages used in the early X-ray tubes would quite satisfactorily radiograph light alloys, they were of little use to founders of the denser non-ferrous and ferrous alloys. The latter require X-ray plants of higher penetration ranging from 100 to 400 kv. according to the thickness they are likely to encounter, or a radium source of gamma rays, corresponding to X-rays emitted by an X-ray plant operating at about 1,500 kv. Industrial X-ray equipment capable of giving 1,000 kv. are in use in the U.S.A.

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* This Paper was also presented to the Metropolitan Chapter of the American Foundrymen's Association, under a special exchange arrangement made by the London Branch and that A F.A. Chapter. The Author, who is Foundry Foreman, Mallory Metallurgical Products, Ltd., was awarded a Diploma for this Paper.

FIG. 3.—STEP BLOCK RADIOGRAPHED BY X-RAYS.

The results of X-ray and gamma ray examination are recorded on a photographic film, a radiograph, which provides a permanent record. X-rays can also be viewed on a fluorescent screen, when the record is non-permanent, and the results are noted by the radiographer at the time of the examination. As this latter method is limited to thin sections of the heavier metals, it does not directly concern this Paper.

A radiograph is obtained through the ability of a percentage of the X-rays emitted by an X-ray tube or the gamma rays emitted by a quantity of radium to pass through objects opaque to light, and then to react on the emulsion of a photographic film, the quantity of radiation reaching the film being governed by the density and thickness of the object being examined. Thus, one inch of aluminium will not absorb the rays and consequently will not reduce their intensity to the same extent as one inch of copper, and the latter will not reduce their intensity to the same extent as two inches of copper.

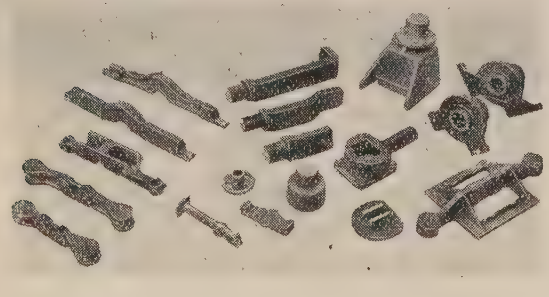

FIG. 4.—HIGH-CONDUCTIVITY COPPER-ALLOY CASTINGS FOR SWITCHGEAR PARTS, REPRESENTING THE LIGHTER TYPE OF CASTING TO BE RADIOGRAPHED. SECTIONS MAY VARY FROM $\frac{1}{4}$ TO 1 IN. ON ANY ONE CASTING.

These variations of intensity reaching the film affect it to different degrees, resulting in what is called photographic contrast on the film. A simple illustration of this is obtained by exposing a film in a light-tight container to a uniform beam of the rays, with no object in their path. On developing the film, no photographic contrast will be seen, that is, the film will be of uniform density over its whole area. If a second film, part of which is now covered by a block of sound metal, be exposed to the beam of rays, the developed film will show a photographic contrast, that is, two distinct densities or shades—dark on the uncovered background, and lighter in the area screened by the block of metal.

If the block of metal contains a cavity, another density will be recorded on the film. This is illustrated in Fig. 1, which is a radiograph of a block of copper containing a large shrinkage cavity. This radiograph will be seen to contain three distinct densities—the dark background, the light area where the rays have had to penetrate the full thickness of metal, and the intermediate shade where, owing to the cavity, the rays have not had to penetrate the full thickness of metal. The difference between the latter two densities is the photographic contrast on which the ease of detection of the cavity depends. The smaller the cavity, the lower is this contrast, and the more difficult it is to see its image on the radiograph.

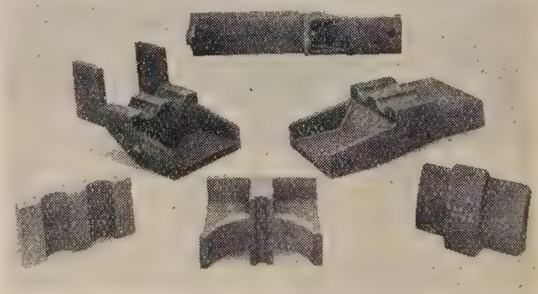

FIG. 5.—HEAVY COPPER-ALLOY CASTINGS FOR ARC-FURNACE CONSTRUCTION, WEIGHING UP TO 3 CWTS. EACH.

Determining Volume and Location of Cavities

To know that a cavity exists in a casting, though useful, is not sufficient to justify the use of radiography. What is important is to be able to determine its volume and position in the casting.

To ascertain the volume of the cavity three dimensions must be known. Of these, the two at right angles to the direction of the rays can be determined by direct measurement of the image of the cavity on the radiograph. In order to determine the extent of the cavity in the direction of the rays, the radiographer aims at a standard density on that part of the radiograph corresponding to the section of the casting it is desired to examine. This standard density is obtained by varying the time of exposure according to the density and thickness of the section. The extent of the cavity can then be determined, by comparison with a set of standard films. Fig. 2 is an example of such films prepared by the gamma ray method. This shows various thicknesses of copper in steps of 1, 2, 3 and 4 in. Each of these steps contained artificial flaws corresponding to 2, 4, 6 and 8 per cent. of the total thickness of each step. The 4 per cent. markers are easily apparent on each step. Fig. 3 was prepared by the X-ray method. This shows various thicknesses of steel in steps $\frac{1}{2}$, $\frac{3}{4}$ and 1 in. Each of these steps had slots machined in it to a depth corresponding to 1, 2, 4 and 8 per cent. The 2 per cent. markers are easily visible on each step.

The location of the cavity in the casting may be found by one of three methods. This factor is important if the normal routine examination has shown a cavity, the size of which does not obviously proclaim the casting scrap.

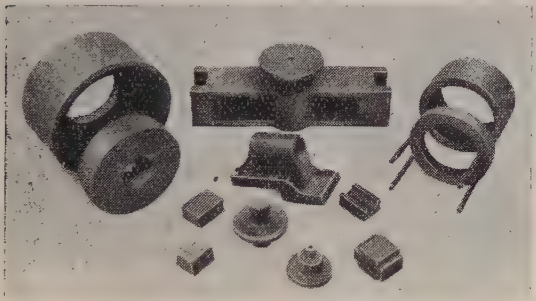

FIG. 6.—HIGH-CONDUCTIVITY COPPER-ALLOY CASTINGS FOR RESISTANCE-WELDING MACHINE PARTS WEIGHING FROM 3 LBS TO 3 CWTS. THIS ILLUSTRATES THE SIMPLE OUTLINE OF HEAVY SECTIONS REQUIRED TO BE CAST FOR THIS PURPOSE.

Of these methods, the most obvious consists in taking another exposure at right angles to the routine exposure. From the two films it is comparatively simple to determine the exact position of the cavity. This method is, however, limited by the shape of the casting, for there may be only one plane it is possible to penetrate successfully.

Of the other two methods, the following involves the use of two extra films and requires a stereoscopic viewing box. Two exposures are taken on separate films through the same plane, the source of the rays being moved a given distance parallel to the film between the exposures. The two films viewed simultaneously using stereoscopic principles give a three-dimensional appearance which allows of judging visually the position of the cavity. This method is particularly useful for the detection of cracks.

The last method relies on a geometric calculation to determine the position of the cavity. One extra film only is required, the exposure being split into two parts, the source of the rays again being moved parallel to the film between the two parts of the exposure. Two images of the cavity will be recorded on the processed film, and its position can be calculated from the distance between the two images of the cavity, the distance the source was moved, and the source to film distance.

Relative Merits of X-rays and Gamma Rays

The photographic contrast obtained with X-rays for thinner sections of heavy metals is very marked, and on work of uniform section thickness, this pronounced contrast proves of great assistance in the detection of small cavities. On castings of varying section thickness, however, this great contrast proves too effective. For example, when radiographing a casting varying by more than about $\frac{1}{2}$ in. in section, the correct exposure is calculated for the thicker section, unless the X-ray beam is heavily filtered, the density obtained on the part of the radiograph corresponding to the thinner section will be so great as to be almost opaque to any but the brightest viewing lamp. Also, scattered radiation from the over-exposed portion will tend to obscure the image on the correctly exposed portion.

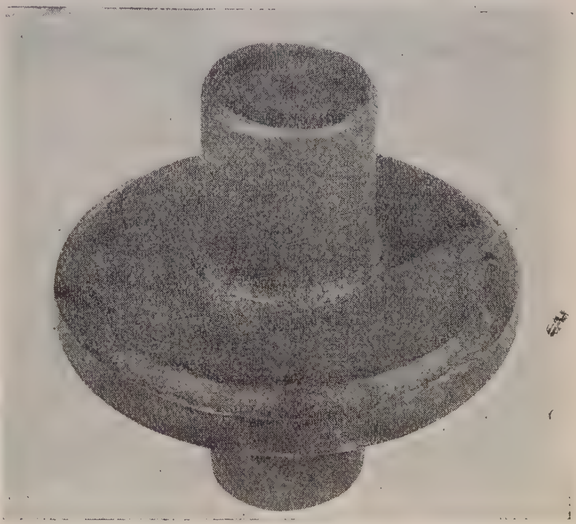

FIG. 7.—A SIMPLE CASTING IN A COBALT-BERYLLIUM-COPPER ALLOY (see FIGS. 8 AND 9).

Various techniques have been evolved to overcome both these difficulties. In principle they are all the same, and consist in building up the casting to an even thickness. On castings with flat faces, sheet metal may be used to build up the thin sections of the casting, whilst irregular castings may be surrounded by metal shot in a container just large enough to cover them.

The photographic contrast obtained with gamma rays is not so pronounced as in the case of X-rays, and this makes the detection of small cavities rather more difficult, as they will not be recorded with such a marked contrast, although it permits of radiographing castings up to about 3 in. change in section thickness without taking special precautions to guard against excessive densities or fogging due to scattered radiation.

Modern X-ray tubes being mechanically cooled are capable of allowing longer exposures than the earlier models. For industrial purposes, however, exposures of more than one hour are rarely given. From this fact, and the fact that the highest voltage plants available in this country are about 400 kilovolts, it is possible to assume that the maximum sections in ferrous and heavy non-ferrous casting alloys which it is possible to radiograph in normal X-ray industrial practice in this country is about 4 in. The actual figures are probably slightly higher for ferrous materials, and lower for copper base alloys.

Exposure times for gamma-ray radiography of thinner sections are considerably longer than for X-ray examination. For example, a 400-kilovolt X-ray tube will radiograph an inch of copper in about 20 secs., compared to an exposure of about 15 min. for a 250 milligramme radium source, all other conditions being equal. This ratio falls very rapidly with increase in section, until at about 4 in. of copper the exposure times are roughly equal at an exposure of about 2 to 2½ hrs.

Gamma-ray radiography is non-mechanical, so that the maximum length of exposure time is governed solely by the length of time that the radium source can be economically spared on any one job; this makes possible such claims as to have radiographed a 12-in. section of steel.

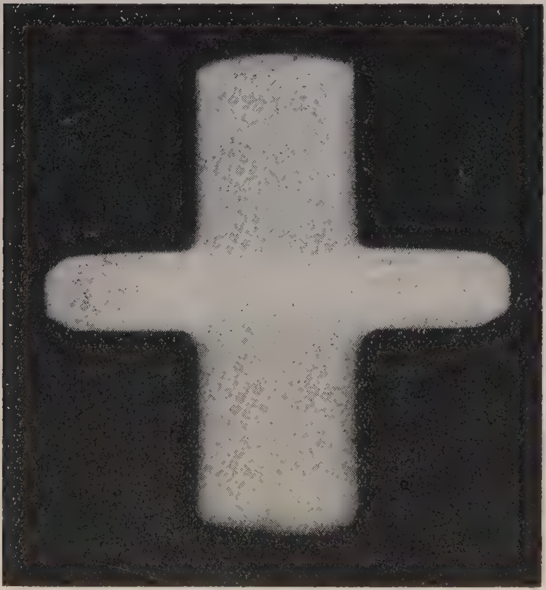

FIG. 8.—GAMMA-RAY RADIOGRAPH OF THE CASTING SHOWN IN FIG. 7.

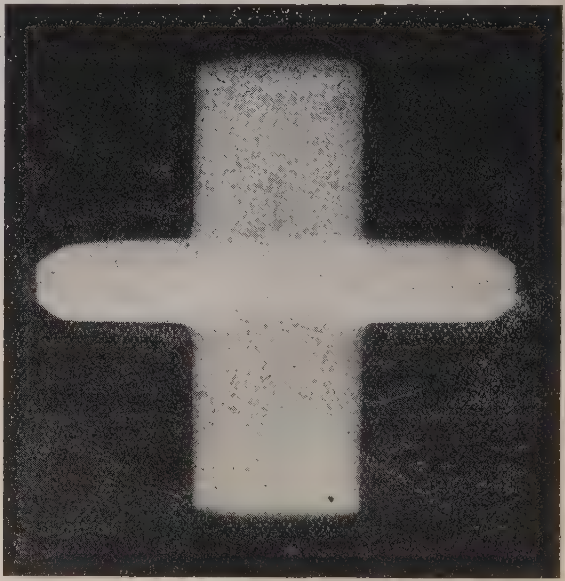

FIG. 9.—RADIOGRAPH OF THE CASTING IN FIG. 7 AFTER ALTERING METHOD OF RUNNING.

Application to High-Conductivity Copper Alloys

The examples to be shown later are gamma-ray radiographs of castings made in a series of high copper content alloys. These alloys, with their particular properties of high electrical conductivity and high strength, were specially produced to make possible the reduction in weight and bulk of castings designed to carry heavy electrical currents, such as switchgear contact bars and current carrying parts of arc furnaces and of resistance welding machines.

To obtain the maximum benefit from such alloys it is obvious that the castings must be sound. A. B. Kinzel sums this up very aptly in the conclusion to his Paper, " High Conductivity Copper Alloys," in which he says: " In the last analysis all of the pre-

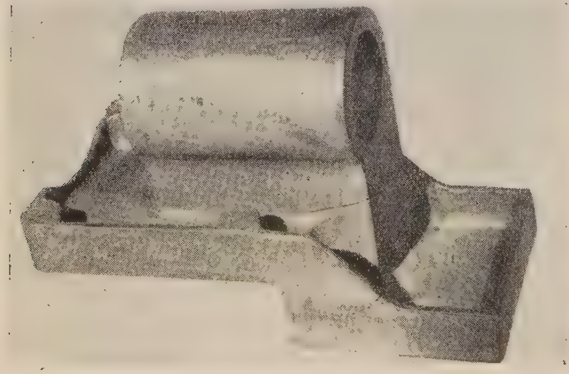

FIG. 10.—CASTING IN NICKEL-SILICON-COPPER, HAVING VARYING SECTION THICKNESSES (*see* FIGS. 11 AND 12).

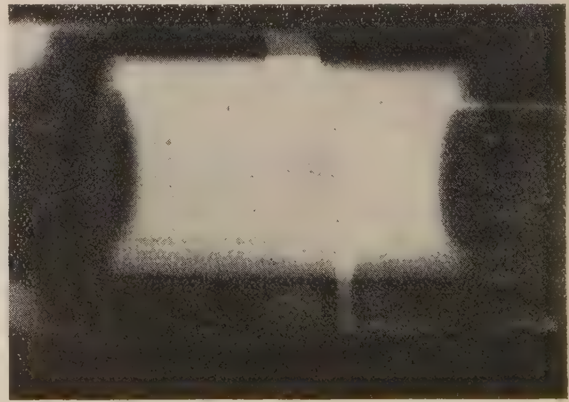

FIG. 11.—CAVITY IN THE CASTING OF FIG. 10.

scriptions and specifications are intended to apply to sound castings, and all of the predictions for high conductivity and high strength are based on the assumption that the foundryman will produce such castings."

In an attempt to achieve this desired soundness, it was decided to introduce radiography in order to give the personnel of the foundry engaged in making castings in these alloys a guide as to the efficiency of the moulding and melting methods practised in the shop.

Fig. 12.—Sound Casting of Fig. 10.

Gamma-ray radiography was chosen for two main reasons:—(1) The varying section thickness and high density of the castings likely to be encountered; and (2) the low cost of examination. The size and shape of the castings were rather difficult to visualise, since with a comparatively new series of alloys the full range of possible applications could not be foreseen. Figs. 4, 5 and 6 illustrate the present range.

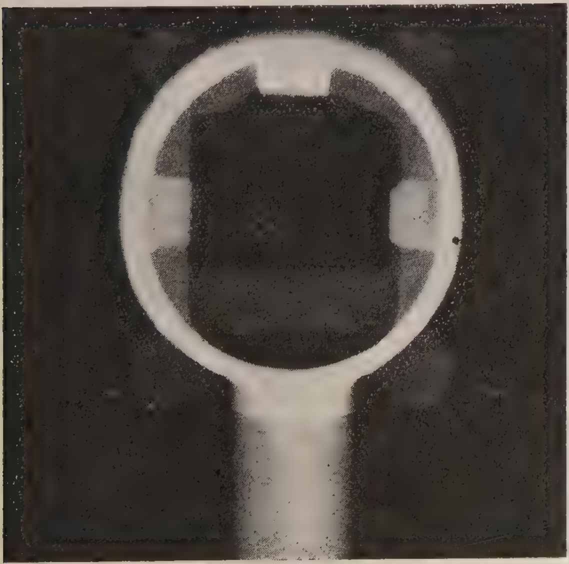

Fig. 14.—Defects in Three Bosses and the Thickening Strip of the Casting shown in Fig. 13.

The section thickness, coupled with the high density of some of these castings, determined very definitely that an X-ray plant below 250 kilovolts would not cover the whole range.

The initial cost of a 250 kilovolt X-ray plant is roughly the same as for a 250-milligramme radium source, but running costs are much lower with gamma rays. In Vol. 47 of the Transactions of the American Foundrymen's Association, the 1939 Radiography Committee quote the following from H. H. Lester's Paper on radiography: "It is possible for the small manufacturer to use gamma rays where he could not afford to maintain an X-ray plant."

Method of Running

The first example (Fig. 7) is rather a stock one, since most foundry text-books point out the possibility of shrinkage at such a joint in sections. Cast in a cobalt-beryllium-copper alloy, this casting was originally bottom-poured through a choke gate in an endeavour to obtain a clean skin, free from oxide dross. A top feeder head capable of containing an equivalent weight of metal to that in the casting was employed to allow for liquid shrinkage. The resulting casting was far from satisfactory, as is shown in Fig. 8. This porosity was eliminated by the use of a mould with a similar feeder head, by removing the small ingate and pouring through the feeder. The sound casting obtained is shown in Fig. 9.

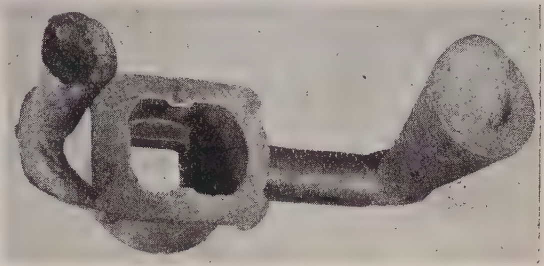

Fig. 13.—Casting in Chromium-Silicon-Copper with Runner and Riser (*see* Figs. 14, 15 and 16).

Position of Feeders

Fig. 10 shows a casting with very varied section thicknesses. The tray is $\frac{1}{4}$ in. in thickness, the bearing walls are $\frac{1}{2}$ in., four of the bolting-down bosses are $1\frac{1}{2}$ in., and the connection between the bearing and the tray varies from 2 to 4 in. of metal. This casting was made in a nickel-silicon-copper alloy, of which the most notable features affecting the making of sand castings are the high liquid shrinkage, and a

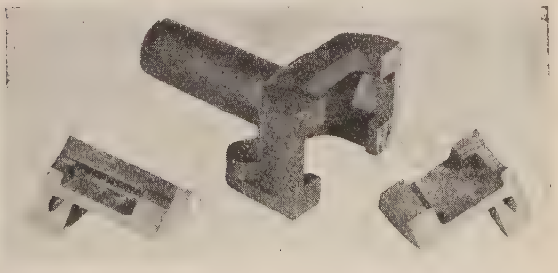

Fig. 14a.—Casting shown in Fig. 14 cut to show Cavities.

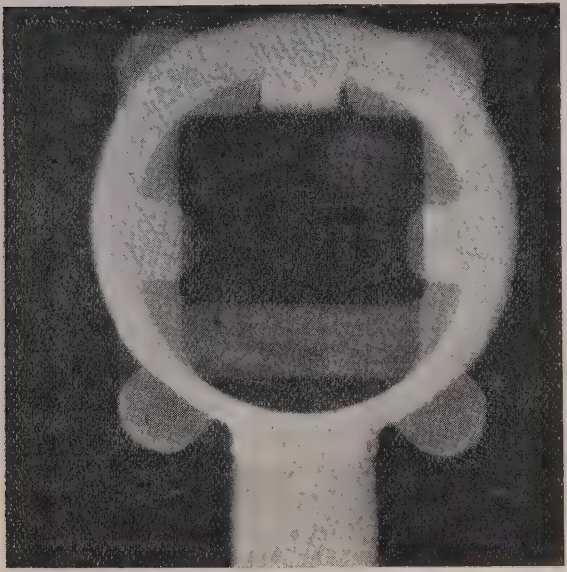

FIG. 15.—POROUS AREA IN WEB OF CASTING SHOWN IN FIG. 13.

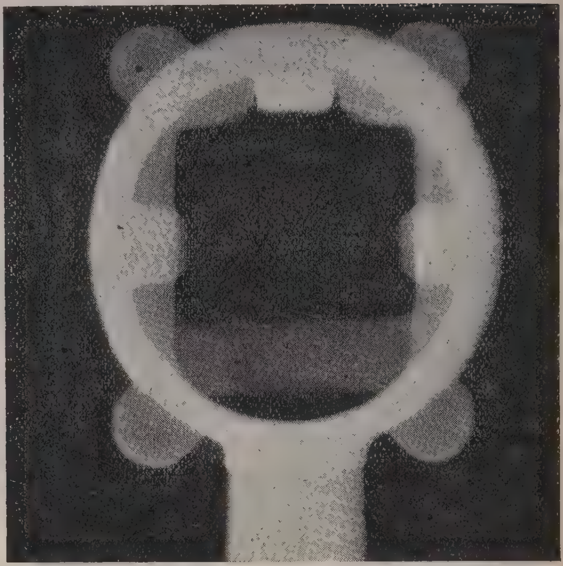

FIG. 16.—SOUND CASTING AS FIG. 13 OBTAINED BY USE OF DENSENERS.

tendency to form an oxide dross during pouring. The obvious points at which to expect internal shrinkage were the bolting-down bosses and the rather heavy mass of metal between the bearing and the tray. The first casting made off this pattern was cast with the tray down, with metal denseners under the bosses, a large feeder running practically the whole length of the bearing, with a sprayed inlet at the lower portion of the mould. The result is shown in Fig. 11. This radiograph shows a large cavity in the metal joining the bearing to the tray. Experience had shown that the size and shape of the feeder were such as to take up the volume of liquid shrinkage likely to be encountered in this casting. It was therefore assumed that the fault must lie in the position of the feeder head. The fact that this was not directly in contact with the section to be fed, but connected to it by the walls of the bearing, raised the point as to whether there was sufficient metal in the walls to remain liquid long enough to allow the liquid metal from the feeder head to reach the thicker section connecting the bearing to the tray. The obvious way to prove this point was to mould the casting the other way up, thus allowing the feeder to be directly in contact with the heaviest section. With a similar weight of metal in the feeder, the casting was obtained quite sound, as is shown in Fig. 12.

Effect of External Denseners

Fig. 13 is a photograph of a casting with runner and riser, made in a chromium-silicon-copper alloy. The box-like end is in ¼-in. metal stiffened up to ¾ in. at one point, the bottom flange is ¾ in., in place of a top flange are six 1 in. dia., 1 in. thick bosses, and the protruding arm is 1¾ in. in dia. This example is chosen to show the practical use of external denseners, a subject which has been a bone of contention at many Institute meetings.

The first casting made off this pattern had denseners placed under the two bosses where the box joins the arm, the inlet sprays were relied upon to act as feeders to the two bosses with which they were connected, and a run-off riser was provided to cover the shrinkage in the arm. The two bosses formed in the core, and the thickening strip down the back were completely overlooked. When radiographed the resulting casting was shown to have defects in three of the bosses and the thickening strip. (See Figs. 14 and 14A.)

The second casting had denseners placed under all the bosses, and one in front of the thickening strip. This meant carrying three denseners in the core, and to avoid deformation of the core in the green state by the weight of these denseners, carbon blocks were substituted for the usual metal ones. The result was as shown in Fig. 15. This casting appeared to bear out the argument that denseners only push the trouble somewhere else, since a porous area can be seen that did not appear in the first casting. E. Longden, in reply to the discussion on his Paper on "Liquid Shrinkage and Contraction," at Manchester, stated that this theory was fallacious. Denseners properly applied with due regard to their position, volume and thermal conductivity, and the changes they will make in the order of solidification of the various sections of a casting, will unquestionably prove him correct; but denseners used haphazardly, such as "Put a chill on that boss, Harry," with no regard to size, probably do lead to movement of porosity from one spot to another.

When making the third casting off this pattern, it was decided to follow up the use of denseners, and a further one was placed under the bottom flange. This resulted in the sound casting shown in Fig. 16.

Fig. 17 is a radiograph of a two inch square sand-cast block, and is included in this Paper more as a curiosity. Cast on end and top poured, this block will be seen to have a pipe, which for some obscure reason does not follow the normal path of such defects in billets, that is, straight down the centre, but deflects towards the wall of the casting at one point. The only feasible explanation of this effect so far offered is that in pouring, the stream of metal must have been playing directly on the side of the mould at this point, and produced a hot spot which delayed solidification there. When this is considered in relation to the fact that in recent years there has been a tendency to go over to top pouring for non-ferrous work, the value of the strainer cup recommended by many lecturers appears to be even more pronounced.

Radiography in Relation to Pressure Testing

Fig. 18 is a radiograph of a water-cooled electrode clamp, in which a small area of porosity can be seen in the thicker section of the metal between the water channels. This casting failed on test. Radiography used on work of this type, apart from its value to the foundry, can save many hours in the machine and pressure testing shops. The particular example shown is one of those exasperating jobs where, for no apparent reason, castings made under apparently similar conditions give erratic results in the test house.

Increasing the size of the feeder heads did not prevent this variation, since one casting with equal metal in the feeders to that in the casting was good. (see Fig. 19), whilst a casting with a ratio of three in the feeders to two in the casting failed on test. Reduction in pouring temperature did not prove to be the solution, but did lead to the most successful change made in production methods, which was to increase the pouring temperature. This gave more consistent results, though the final solution was found to lie in a change in the design of the water chamber.

This Paper was prepared in an attempt to indicate the manner in which radiography can be of assistance to a foundry. It is rather paradoxical that in endeavouring to make this clear, emphasis has of necessity been placed on the radiographs of unsound castings. In deference to the foundry trade in general and to the shop concerned in particular, it must be made clear that this fact in no way implies that all new designs necessarily mean bad castings in the first instance.

The introduction of radiographic examination into a particular foundry brings into prominence the problem of what constitutes a good casting. It will be evident that some guide as to the flaws permissible will have to be drawn up for the assistance of the inspection department. No single standard could be fixed covering castings as far removed from one another as structural members of machine tools and Diesel cylinders, for obviously the use to which a casting will be put in actual service must govern the extent of the flaws permissible in that casting.

In conclusion, the author wishes to thank the directors of Mallory Metallurgical Products, Limited, for permission to present this Paper, and to use examples of their products, and Kodak, Limited, for permission to publish Fig. 3.

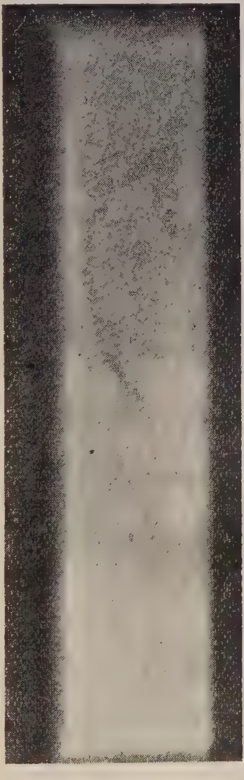

FIG. 17.—GAMMA-RAY RADIOGRAPH OF A TOP-POURED 2-IN. SQUARE BLOCK. THE PIPE IS DEFLECTED TOWARDS ONE WALL OF THE MOULD.

DISCUSSION

The BRANCH-PRESIDENT (Mr. R. B. Templeton), said he did not like the word "cavity." The word "cavity" suggested a definite hole, and there was a very wide range of structure between a hole and a close-grained structure within which a casting might fail under pressure test. A cylinder head, for example, might not have an actual cavity inside it, but its grain structure might be so open at some point that it would fail under pressure test. He asked whether radiography would indicate this difference of structure and make it sufficiently visible to the eye to enable one to decide whether or not the casting was quite sound everywhere.

Radiography was definitely of value from the quantity production point of view. If one were producing 3,000 to 5,000 of a certain casting, it would certainly pay to take a radiograph of the earlier samples, as one would be able to decide whether or not it was a border-line case. If the radiographs showed it was a border-line case and the moulding technique and the metal control were correct, then any slight variation in the metal control during the subsequent production would probably render the production job a failure. If, on the other hand, the radiograph showed that the sample was sound, then one would have a margin to cover any subsequent variation in the metal control or moulding technique. Apparently there was not quite so much advantage in the use of radiography in connection with jobbing work, except where one had to produce a special casting; and he asked if Mr. Gladwell would agree that in such a case it would be necessary to take a whole series of radiographs of the casting.

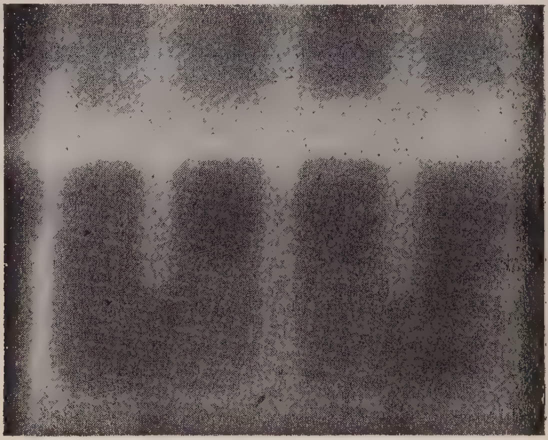

FIG. 18.—A GAMMA-RAY RADIOGRAPH OF A WATER-COOLED ELECTRODE CLAMP SHOWING POROSITY IN THE THICKER SECTION BETWEEN THE WATER PASSAGES.

MR. GLADWELL replied that perhaps he had made use of the word "cavity" because he was concerned with non-ferrous castings; non-ferrous castings sometimes had cavities, and those cavities were inside; they might be due to casting conditions or to shrinkage. Further, castings in high-shrinkage ferrous metals sometimes looked quite well on the outside, but there were cavities inside. Manganese bronze castings very often showed a draw on the outside, but the high-copper-content alloys did not exhibit that feature to the same extent. As to whether radiography would enable one to see the grain structure sufficiently to be able to decide that it was just sufficiently unsound to warrant the scrapping of the casting, Mr. Gladwell said that, given an even-section casting, good illumination and a good viewing screen, the radiograph ought to show the change in density of the metal.

MR. R. L. DURANT, dealing with the Branch-President's question concerning the use of radiography in production foundries, said that the light alloy interests had done a good job in working out the best method of using radiography in production, and they had been using it for quite a long while. The value of radiography in a jobbing foundry must depend on the type of work that was being done.

Acceptance or Control Test?

MR. V. C. FAULKNER (Past-President of the Institute and of the London Branch, and Hon. Secretary of the Branch) was still convinced, after having heard Mr. Gladwell's Paper, and many others previously, that the use of radiographic pictures for the purposes of an acceptance test was undesirable. That view was held by the Railway Companies and by most of the inspecting authorities. At the moment, far too much depended on the interpretation of the pictures, and he still regarded it as solely a control test. At the same time, the use of radiography had been developed to a great extent in the light alloy industry, so much so that the castings were brought to the viewing screens by conveyor.

MR. GLADWELL replied that his firm had decided to use radiography because they were tackling alloys to which they were not then accustomed, and had to make good castings in those alloys. Although, before the use of radiography, he had thought that the castings were good, he had cut up some of them and had found that they were not so good as they should be; indeed, it had been suggested, perhaps facetiously, that he had been making those castings for three months before he had been able to make a good one. Radiography was adopted because of the initial troubles, and since its adoption some good castings had been made. He would not discuss as to whether or not an authority such as Lloyds should use radiography as an acceptance test; but the A.I.D. had a radiographic test for castings, and certainly the A.I.D. wanted good castings. He was not out to claim that radiography provided the finest acceptance test, but that it was a valuable medium of assistance to foundrymen. Too often foundrymen in the past had complained that, although there was a laboratory stuck on the end of the foundry, all the reports on castings went there and stayed there, and probably the foundrymen never saw them. He had been told that 50 firms in this country were using radiography; and he urged that the radiography department should always inform the foundry whenever radiography showed that a casting was not all that it should be. Only in that way could the foundrymen be expected to put matters right, and they were willing to take advantage of it, if it were used to assist them and not merely as a means to enable someone else to blame them and scrap their castings.

"Shadowgraphs"

MR. J. F. KAYSER urged that radiography was so important to foundrymen that the Institute would not be overdoing it if, say, 25 per cent. of the Papers presented during the next two or three years were devoted to that subject. It was not necessary for foundrymen to know very much about the apparatus itself; he did not think it was necessary for the foundrymen to know more about the X-ray apparatus than one should know about a camera for the purpose of taking good photographs. That did not imply, of course, that the user of X-rays should be downright ignorant about the apparatus; but it was rather unfortunate that many who had discussed the application of X-rays in the past had devoted far too much time to a consideration of the electric circuits, the particular types of condensers they used, the cooling systems, etc. The foundrymen did not need to be troubled with that sort of thing, but wanted merely a piece of apparatus which would produce shadowgraphs of their castings. Incidentally, the whole problem was much simpler if one regarded the pictures simply as shadowgraphs, instead of "radiographs."

In a criticism of some of the shadowgraphs exhibited, Mr. Kayser suggested respectfully that those responsible for them had not chosen quite the best angle from which to "shoot" them. In general, he said, one could not obtain much information from what might be called a "normal shot." For instance, using an ordinary chair with which to illustrate the point, he said the most useful shot would not be one taken straight down through the seat or straight across it, because one would experience trouble in dealing with the angles and corners; it was necessary to take the picture at an angle of 45 deg. or thereabouts. It was really very important to select the right angle for each shape of casting. Some of the shadowgraphs exhibited seemed to be inconclusive; the radiographers had attacked one part of a casting, but had not attacked what he believed to be the real danger zone.

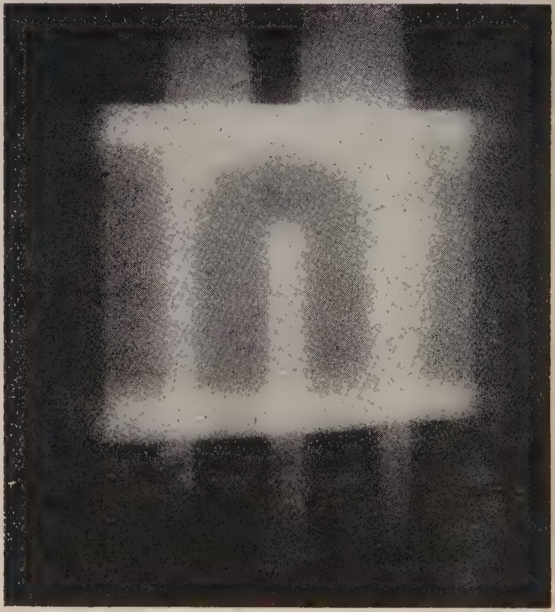
FIG. 19.—SOUND CASTING OF FIG. 18 TYPE.

Care must be exercised to ensure that progress was made along the best lines in developing X-rays for use in the foundry, because, although X-rays had been known for a very long time—he believed the first X-ray tubes were made in 1896—the science was, in a way, still in its infancy. The nomenclature also must be definite. When referring to the "screen," the fluorescent screen or intensifying screen was indicated, as distinct from a sheet of lead which was used to screen off the rays from the operators; it was usual nowadays to refer to the latter as a "filter."

Blowhole Detection

Commenting on whether or not one could detect a cavity in a casting by means of X-rays, Mr.

Kayser said the answer did not depend on the absolute size of the cavity; it was a matter of the size of the cavity relative to the thickness of metal in which it was enclosed. In the examination of light alloys a careful operator could detect a change of section of only 2 or 3 per cent. It might not be an abrupt change of section due to the presence of a blowhole; it might be due to porosity, and one needed a good deal of experience in the interpretation of results to be able to detect the difference between a general porosity and just one blowhole or cavity.

It was rather difficult to determine the position of blowholes or cavities with the aid of only one shot, because there might be two cavities, one above the other; in a normal shot one could not determine their position by the intensity, nor could one determine the dimensions, because the two cavities would register as one.

As to whether or not X-ray pictures should be used for the purpose of acceptance tests, he agreed with Mr. Faulkner that they should not be so used, in the present state of knowledge and the state of the art. At the same time, it was valuable as an aid to successful production. His own firm bought many castings, but they specified quite definitely what they wanted, so that there was no argument about it; they would not buy certain classes of castings from a firm which had not an X-ray set or, alternatively, which did not use one of the commercial institutions liberally. When dealing with a foundry of repute, one need only specify that the castings required must be suitable for the manufacture of certain products, which might be fireplaces or diesel engine cylinders. If the founders produced castings which were not suitable, owing to the presence of cavities, and so on, it was their funeral. But if the buyer doubted the integrity of the founder, then there should be an acceptance test. He urged that every foundry should have an X-ray apparatus, just so that they should know what they were doing.

MR. GLADWELL agreed that it was not easy to decide the angle from which to take a radiograph of a casting. With regard to a cavity, he had not claimed that one could determine its position from a single radiograph. A second exposure was necessary, and if the time of the second exposure were reduced, the images would have slightly different densities; by moving the apparatus a little for taking the second exposure, it would be sufficiently out of line to show whether or not there were two cavities. But that was purely a matter for the radiographer, and a foundryman did not need to be a radiographer.

MR. DURANT, who was invited by Mr. Gladwell to answer the question concerning cavities, agreed that two cavities in line would show as one. But if the image indicated a cavity, one might decide that it was so near the middle of a thick section, and away from any changes of section, that its presence would not matter, from the point of view of the efficiency of the casting in use; and even if there were two small cavities, that fact might not affect the decision. But if a cavity were in an awkward position in the casting, the operator would probably radiograph it from a second angle; then, if there were two cavities, he would detect them, and would be able to decide whether one or both were bad from the point of view of the use of the casting.

MR. R. TURNER said that the radiographs exhibited had been selected rather carefully, from the point of view of their interest to foundrymen. He agreed that it was important to select the right angle from which to take a "shot," and added that in some cases one could consider just one spot on a radiograph for quite a long time before one could decide whether or not it was necessary to change the method of producing the casting in question.

MR. KAYSER agreed with Mr. Turner, and said he was merely anxious to emphasise that it was important to choose the right angles when using X-ray apparatus.

High-Conductivity Copper

MR. G. C. PIERCE (Past Branch-President) complimented Mr. Gladwell on the fact that, whereas he might have chosen to present a highly academic Paper—which many foundrymen did not like—he had in fact dealt with his subject in a manner which every foundryman could understand. His heart went out to Mr. Gladwell when the latter had mentioned the difficulties experienced in casting really high-conductivity copper. Any foundryman who was making castings in copper of really high conductivity, in the region of 84-88 conductivity (as distinct from copper of ordinary conductivity), would find, not only blowholes, but real cavities in some of those castings; and there was no doubt that they were real cavities. He wished Mr. Gladwell had exhibited a radiograph showing the porosity found ordinarily in high-conductivity copper.

Recently, continued Mr. Pierce, he had been considering the use of the shadowgraph for determining the utility or otherwise of castings, particularly of copper, for he supposed that the cost of determining whether or not a casting was thoroughly sound by means of a volume conductivity test would be higher than the cost of a shadowgraph test; the calculations involved in a conductivity test on a highly irregularly shaped casting could be very complex, though it was quite simple to make a conductivity test on a 2-in. sq. bar. A shadowgraph might show whether or not the copper contained anything which should not be there; and there were not too many ingredients that one could use to maintain the conductivity of copper whilst at the same time ensuring the production of sound castings. He asked whether the use of the shadowgraph was an economic proposition in foundries dealing with speciality alloys.

MR. GLADWELL replied that, although he had not shown radiographs illustrating the sort of trouble to which Mr. Pierce had referred, he certainly had some of them; the casting of high-conductivity copper gave rise to a good deal of trouble. Radiography was reasonably cheap; it might be thought that the initial cost of the apparatus was the real difficulty, but that could be dealt with quite well. Before the war it was possible to hire the apparatus, and it was quite useful to be able to do that when dealing with speciality castings.

MR. PIERCE said he believed that very high-conductivity copper castings were designed very much heavier (to ensure that the required conductivity would be achieved) than would be the case if the designers knew that the castings would be completely sound.

MR. GLADWELL agreed that radiography was useful in enabling founders to limit the weight of their castings; and he added that, the heavier the section, the worse the trouble was likely to be.

A Different Perspective

MR. C. H. KAIN (Past-Branch-President), after thanking Mr. Gladwell for having indicated one more step in the direction of the precision inspection of castings, commented that radiographic examination seemed to be still in the stage of diagnosis. Both Mr. Faulkner and Mr. Gladwell had intimated that there must be agreement on permissible flaws; but Mr. Kain disliked that attitude intensely, and expressed the hope that the radiography engineers would soon be able to provide equipment with the aid of which one could guarantee perfect castings. Undoubtedly the secret of quality in castings was rigid inspection.

During the last six months we had witnessed the rather startling developments of the atmospheric head, which was given much publicity in the American Press, and the whirl gate head, which was developed in this country, and the results obtained with the high-shrinkage steels were really quite remarkable. He could see no reason why foundrymen should still be worrying about the permissible flaws as shown in radiographs; they had to make the perfect casting, and it was up to the radiographer to provide an instrument which would give precise information.

He had been told by his friends in the light alloys industry who employed radiography very extensively that they were still, unfortunately, at the stage where they might have to make as many as 500 radiographs of a new part before they could be perfectly satisfied of the correctness of the diagnosis of what they saw on the graphs. It seemed to him that there were two attitudes towards the use of X-rays. The first was illustrated recently, within his experience, when medical men, after studying an X-ray photograph relating to a patient who was seriously ill, had shaken their heads very learnedly and solemnly and had walked away. That, he said, represented the attitude of the foundryman. Then there was the attitude of the engineer, who seemed to think that X-ray examination provided the answer to all questions, though certainly it did not. He could see no difference between the examination of production castings and of jobbing castings. Surely in the course of time there would be available instruments, with a capacity approaching 1,000 kv., which could be installed and used for routine inspection.

Commenting on Mr. Kayser's view that engineers should specify merely that the castings they ordered must be suitable for the job they had to perform, Mr. Kain suggested that that was undesirable, because it meant throwing the foundrymen into the realms of diagnosis as to what was suitable and what was not suitable. Foundrymen must ask for precise information as to the requirements which their castings were to meet; they wanted the engineer to state that the castings he required must meet certain requirements, and must conform to certain measurable constants. X-rays should help the foundrymen to produce the castings required.

Inspection Difficulties

MR. A. J. MURPHY, M.Sc. (Vice-President), uttered the warning that they in the foundry industry would make a great mistake if they tried to transfer to someone else the responsibility for decisions regarding the quality of their castings. The light alloy industry, producing castings for aircraft, had made most frequent use of the X-ray method of inspection, and it was instructive to recall the principle which was followed in that field. Those who signed certificates relating to the X-ray examination of castings for the aircraft industry were required to certify that the castings were free from major defect. The technician of the foundry company had to do that, and if he used the X-ray method for that purpose he must use it in the best possible way. Mr. Murphy added that he did not know of any case in which it was reasonably possible for any outside authority to put forward a precise specification as to the quality of castings as revealed by radiography: one could not define numerically the features one saw in a radiograph. Sometimes in production jobs, where many of exactly the same article were made and where there were many radiographs exhibiting a certain feature, it was possible to correlate that feature with a certain quantitative deterioration of mechanical properties. But the more experience one had of doing that, the more hesitant one became to do it if it could possibly be avoided.

The Paper had dealt with the radiographing of castings in copper alloys, which were different from the light alloy castings used in aircraft. The latter had generally to withstand stress in use, and it was necessary to know whether they were of sufficient quality to withstand the stress to which they were to be subjected. Presumably that was not so in the case of the castings discussed by Mr. Gladwell, whose purpose was to ensure that those castings would not prove to be defective after expensive machining and would not fail under pressure test.

MR. GLADWELL agreed that that was so. But it was necessary also to ensure mechanical strength, particularly in the case of the switchgear type of castings.

MR. MURPHY, referring to the use of X-rays for checking the quality of new production, said it was important to maintain a balanced mind in regard to that. The great value of X-ray examination was that it was non-destructive; it was an alternative to sectioning and fracturing castings for purposes of examination. There was no particular merit in the X-ray method *per se* as applied to castings; but it had the great advantage, in connection with production, that it was convenient and non-destructive.

Percentage Inspection

Asking for information as to the percentage of the total castings that were X-rayed in any batch, MR. MURPHY said that one sought a method of batching which would give a logical connection between the number that had to be examined and the number that were governed by that examination of the minority. In some cases the practice was to examine radiographically the first 10 or 20 castings or such other numbers as were necessary to obtain 10 consecutive castings free from major defects. That was held to confirm the correctness of the foundry method, and then it was possible to fall back on less than 100 per cent. inspection, the actual percentage depending on the nature of the job.

Emphasising the value of external inspection, coupled with X-ray examination, he said that in very many cases it was possible to see some slight indication, on the external surface, of a defect which would also be revealed, and more clearly revealed, by X-ray examination. His company attached very great importance to the interpreter of the radiograph making also a very close visual inspection of the casting. That visual examination enhanced very greatly the value of the X-ray examination, and gave indications as to where one could concentrate with advantage the X-ray examination. Finally, Mr. Murphy asked for Mr. Gladwell's experience as to the value of the X-ray method for the detection of cracks in castings of pure copper and the copper-rich alloys which he had described.

MR. GLADWELL, replying to the question concerning the percentage of castings that were examined in any batch, said that in the majority of cases with which he was concerned it was necessary only to produce a few in each batch, so that 100 per cent. radiographic examination was possible. But where a considerable number had to be made, the method was to settle the casting procedure with the aid of radiographic examination, and to adhere to that procedure. He had had no experience of the use of radiography for the detection of cracks; when a crack occurred, it was usually one that could be seen quite easily.

A Medical Analogy

Mr. P. T. Holligan recalled that he had been concerned, some years ago, with the examination of welded pressure vessels, having walls about 2 in. thick, and all of them were X-rayed. Incidentally, in that case an acceptance test was adopted by Lloyd's Register, which was the specifying authority, and was accepted by the manufacturers, and it was that fact which had enabled welded pressure vessels to go into service. The purpose of the test was to detect, not only slag inclusions and porosity in the weld metal, but also cracks, and the latter was a matter of very great difficulty. In one particular case there was a crack running parallel to the direction of the rays when the "shot" was made. It was probably only one-tenth of a thousandth in. (0.0001 in.) wide, and one could not expect to detect it when the rays were parallel with it. A "shot" taken at right angles also would not show the crack, because the actual reduction in density was considerably less than the 1 per cent. which was regarded as the sensitivity factor of X-rays at that time. That experience suggested that it was very difficult to detect cracks by X-rays.

Emphasising the point made by Mr. Murphy concerning the importance of examining the surface of a casting in addition to the radiographic examination, Mr. Holligan recounted the experience of a friend who had been X-rayed. The doctors had pointed to a shadow shown on the shadowgraph and had said that there must be something gravely the matter with him. He had pointed out that he had been X-rayed from the front, whereas a scar was on his back; and the doctors were annoyed because he had not told them about it previously. That story perhaps pointed a moral to those who were radiographing castings!

Mr. W. D. Gist, expressing appreciation of the value of the X-ray examination of castings, said that sometimes, when he had exhibited examples of the sort of defects which it detected, the foundrymen to whom he had shown them had expressed thankfulness that their own castings were not X-rayed, because they felt sure that some of their castings would not stand up to it. One valuable use for radiography in the foundry was to enable foundrymen to determine whether or not their method of casting was satisfactory. Inasmuch as it indicated the types of defects, it enabled the foundrymen to try other methods to overcome those defects; and it was not unusual for them to try half-a-dozen different methods before they were able to produce satisfactory castings. In his experience they could eventually produce good castings, no matter what type they were, if they tried hard enough and long enough and had the advantage of X-ray examination. X-rays could also be used as a method of inspection, but in his view that use was not to be encouraged. It was expensive and totally unnecessary, because its use by the founders had already ensured that the castings were good.

The Branch-President, at the conclusion of the discussion, said it was useless making a really good metal, and then spoiling its value by faulty foundry technique. The value of X-ray examination was that it enabled foundrymen to ensure that their technique was good, for it was a final arbiter of the soundness of the castings. A test-bar might show that the metal had a tensile strength of 20 tons per sq. in., but if there were porosity in the casting, it was not up to specification.

Scottish Branch—Falkirk Section

Paper No. 780

Acid Resistance and Technical Control in an Enamelling Plant[*]

By W. MONTGOMERY[†] (Associate Member)

Generally speaking, acid resistance, as defined in this country, is a purely relative term. To some it means resistance to attack by industrial atmospheres, to others, resistance to the action of organic acids—mostly fruit juices; while to a select group of enamellers it infers the complete passivity of an enamel to most known acids, organic and inorganic. In this Paper, the term "acid resistance" with reference to vitreous enamel implies that the material is inert to the action of all organic and mineral acids, with the exception of hydrofluoric acid and its salts, and possibly phosphoric acid of certain concentrations.

Such a material has valuable attributes which, in some cases, make it superior, in the field of chemical resistance, to even the modern synthetic resins or plastics. All these latter substances are soluble in some organic liquids, which limits their range of usefulness to the chemical trade. Metals of the "stainless" type also show excellent resistance to the corrosive action of certain chemicals but, of course, the scope of their applications is limited, while in the present emergency the limiting factor is often the imperative need to conserve valuable metals.

Thus, from the chemical engineer's viewpoint some materials cannot be considered, others have limited applicability, and a few stand high in his estimation as giving chemically-resistant engineering surfaces. In this latter category falls acid-resisting vitreous enamel. When suitably produced, these enamels are astonishingly resistant to corrosive conditions and are being increasingly used in the chemical, pharmaceutical, food and allied trades where freedom from contamination of the product is essential.

Some Advantages of Vitreous Enamel

In a reaction vessel where a chemical may be precipitated or in a tank in which milk is stored, it is a decided advantage to be able to clean out the container regularly and efficiently. With a glass-lined vessel such an operation is simplicity itself. Contamination of the product is, for all practical purposes, virtually eliminated as the solubility of these boro-silicate glasses or vitreous enamels in acids of all concentrations is negligible. The heat transfer characteristics of these enamels are of a high order. Rubber linings, plastics and cements often leave much to be desired in this connection.

In spite of being relatively brittle and non-ductile, these enamel linings in steel and cast-iron vessels will withstand a surprising amount of abuse, although, it need hardly be said, the wise user of a glass-lined vessel will not drop a 10-lb. hammer on to its surface. Actually, the strength of a composite is determined by the strength of the bond, and this factor is well known to be quite satisfactory in a well-balanced enamel properly fused on to a metallic base. Quite rightly, the appearance of vitreous-enamelled ware is often stressed and it may be stated that in developing the utilitarian properties of the enamel, the æsthetic side need not be neglected. High gloss and good finish are necessary prerequisites in acid-resisting enamel glasses. Fast pastel colours are usually used while the ubiquitous mottled finish is, for obvious reasons, dispensed with.

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[*] The Author was awarded a Diploma for this Paper.

[†] Works Chemist and Metallurgist, Henry Balfour & Company, Limited.

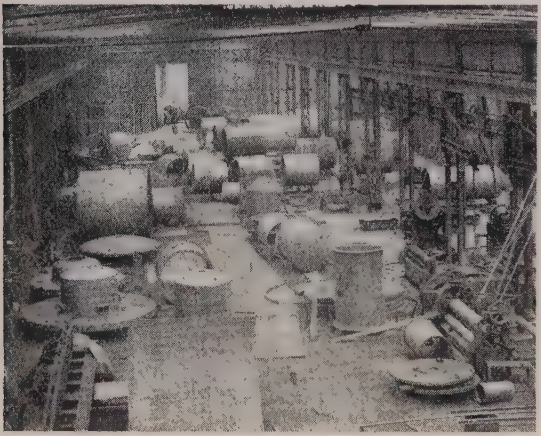
FIG. 1.—FABRICATING SHOP FOR GLASS-LINED VESSELS.

The broad principles of applying these silicate coatings to metals are, of course, widely understood, but into the processing of acid-resisting enamels, on an industrial scale, there creep certain difficulties. The glass (and these silicates are true glasses) is usually more viscous at firing temperatures, and hence less easily "worked" than the lead-bearing porcelain enamels. A certain degree of ease of application is sacrificed in attaining good resistivity. These practical difficulties are overcome in plant operation by the application of rigid technical control and the imposing of a standardised procedure at every stage of the process. Designers of enamelled ware must co-operate fully with the works personnel, as well as with the laboratory.

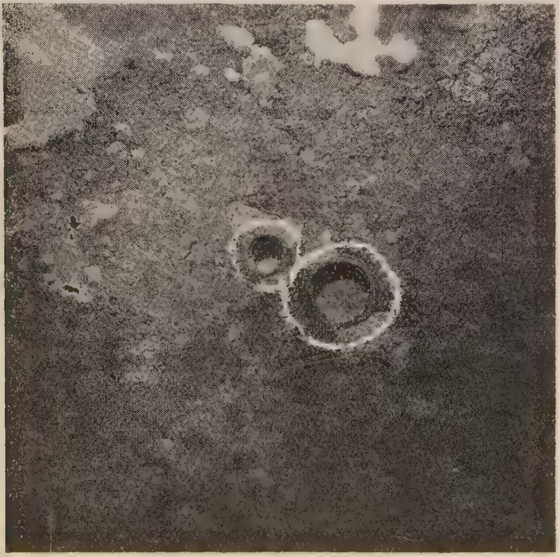
FIG. 2.—STEEL SURFACE FLAWS.

Scientific investigations have contributed as much to the glass and enamel industries as to any other industrial development. Although the industry has progressed a long way beyond the primitive efforts of the early Chinese or Egyptian enamellers, it would be untrue to say that modern scientific control has entirely eliminated the personal equation from the enamelling plant. The practical enameller is still a craftsman and in the final count it is his work which makes or mars a job, although most of the empirical practices have been eliminated.

Composition of Base-Metal

The choice of the base-metal may be either steel or cast iron, the governing factors being size, weight, and design of vessel. In the case of steel, technical control starts with the careful choice of raw material. Acid open-hearth steel is demanded with a maximum carbon content of 0.15 per cent., and other impurities in the stock used must be as low as practicable. Cast-iron enamellers might well ask why such a low carbon content is specified for steel enamelling stock, when they are regularly using irons with over 3.0 per cent. carbon.

It must be realised that, apart from dissolved gas, slag and oxide inclusions, the main factor governing the ability of a steel to take an enamel is its microscopic structure; taking 0.83 per cent. carbon as the eutectoid composition, and remembering that one part by weight of carbon yields approximately 15 parts of cementite, and that 1 part of cementite is equivalent to 8 parts of pearlite, it may be seen that the microstructure of a 0.15 per cent. carbon steel will reveal 18 per cent. pearlite and 82 per cent. ferrite. Given the above percentage of pearlite, 2.25 per cent. of iron carbide would be present.

Using similar reasoning it will be noted that a steel containing 0.50 per cent. of carbon will in the microstructure show 60 per cent. of pearlite, the remaining 40 per cent. consisting of free ferrite, taking for granted, of course, that equilibrium conditions prevail. The point to be emphasised is that with a small increment in carbon percentage a relatively larger increase in the amount of pearlite present may be expected. In steel, the presence of appreciable quantities of pearlite always leads to enamelling troubles. Even ignoring the increased volume change which it gives rise to at the eutectoid temperature, it can be accepted as fact that the presence of eutectoid iron carbide at temperatures slightly under 700 deg. C. causes blistering on the enamel layer. Without entering into a detailed discussion of these phenomena, it may be stated that iron carbide may be oxidised by moisture in the enamel slip to form either hydrocarbons or molecular hydrogen, depending on the decomposition temperature. Hydrocarbons break down completely

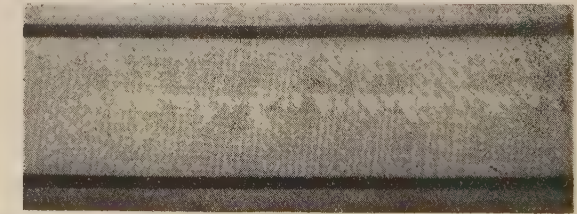
FIG. 3.—RADIOGRAPH OF BAD ENAMELLING WELD.

at about 600 deg. C., and hydrogen may be liberated in quantity at the enamel-metal interface.

Technical Control in Production

To illustrate how technical control plays a part in every operation, a brief resume will be given of the sequence of production from steel plate to finished vessel. The design and size of the latter make mild steel the natural choice for the enamel base in the majority of these articles. It can be taken for granted that the rigid control in the operations described hereafter are just as applicable to, and in some cases more neçessary for, cast-iron enamelling.

It is stipulated that all steel enamelling stock must be under 0.20 per cent. carbon and be produced by the acid open-hearth process. The chemical composition is carefully checked by the laboratory on all incoming materials and, quite apart from the carbon content mentioned above, the minimum of impurities must be present. A view of that section of the boilershop where enamelling stock is fabricated is shown in Fig. 1. The plates are cut, shaped, and welded here after inspection to ensure the absence of cracks, laminations, rolled-in mill scale, and any similar extraneous flaws. A small undetected lamination in a plate at this stage assuredly leads to enamelling difficulty at a later period. Fig. 2 shows the type of surface flaw which must be eliminated. Small round pieces of slag or oxide were rolled into the hot plate at the mills; the pieces can be readily picked out, but the little cavities left cause trouble out of all proportion to their size.

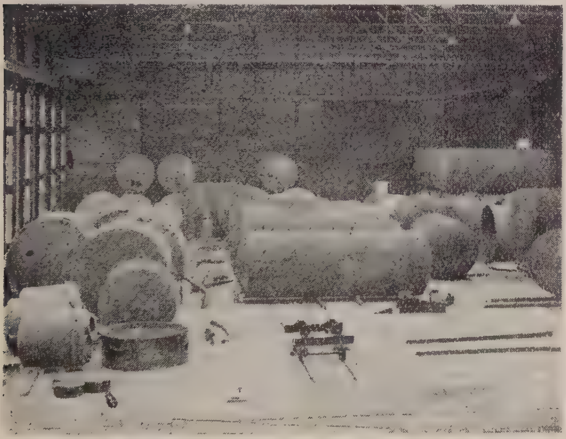

FIG. 4.—ENAMELLING SHOP (WET-SPRAY METHOD).

One of the most prevalent causes of enamelling defects is to be found in "gassy" welds. Where the weld deposit has failed to penetrate to the root, cavities are formed which favour the enclosure of trapped gases. As these inclusions are always below the surface of the metal, it can only be deduced that diffusion of the gas to the surface has taken place at the high enamelling temperatures involved. The author believes that hydrogen is mainly responsible. For the inspection of welds in enamelling vessels radiography has proved a boon. Radiographs taken on a seam after welding may save much time and money in blasting, furnacing and enamelling by continuing to process faulty material. X-ray examination of each seam eventually became unnecessary in the author's plant as the welders, with X-ray aid, perfected their technique until only investigational work called for radiographs. Fig. 3 shows a typically poor weld from the enameller's viewpoint.

The fabricated components are next given a preliminary normalising treatment at the enamelling temperature which relieves stresses in the metal, and those due to previous rolling and welding operations. Dissolved gases may, at this stage, be diffused to the surface and partially expelled, while surface grease and oil are burned out.

The parts then pass to the sand-blast chamber, where control of the operations aids greatly in maintaining a steady throughput. Quartz grains are used in preference to chilled grit and this, naturally, entails the inclusion in the plant of protective measures for the operatives. Much has been written about the principles and technique of sand-blasting but this particular unit is of the modern automatic type in which the fines are separated from the used grains and the latter returned, after screening, to the main chamber. Medium or low blast pressures are used to prevent undue shattering of the sand particles. The size and shape of the grains are controlled from day to day by laboratory sieve tests and microscopic analyses. This sand-blast chamber also plays an important part in de-enamelling operations. The nature of the work precludes the use of alkali baths in this connection and enamelled surfaces usually receive, while hot, a spray quench prior to sand blasting as this renders the enamel friable and easier to remove.

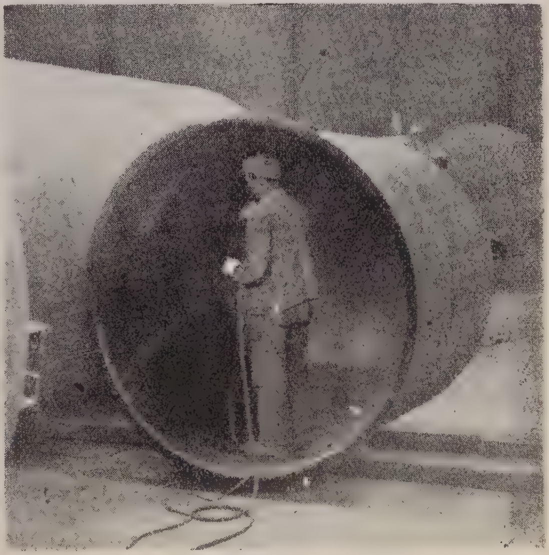

FIG. 5.—SPRAYING A VESSEL.

In the main enamelling shop, shown in Fig. 4, the vessels are sprayed for firing and fitted for despatch. A supply of hot air is drawn from recuperators on top of the furnaces and led through conduits into the sprayed tanks in order to drive the moisture from the slip as quickly as possible. Fig. 5 shows a sprayer manipulating a compressed air spray-gun inside a vessel, and although the man is aided by having scientifically set-up enamel, quite a modicum of skill is required to apply the wet slip in such a manner as to avoid trouble in firing. He knows just where the enamel should be applied a little thicker; where it is necessary to have fine and even application; and, above all, to detect any surface blemishes and remove them prior to the application of a ground coat.

Furnacing

The factory with which the author is associated possesses the finest enamelling furnace of its type in the country. Vessels can be accommodated up to an overall size of 20 ft. in length and 12 ft. diameter. Such a tank would weigh approximately 9 tons and have a capacity of 15,000 galls. As an approximation, it may be stated that 4 tons of trebles will provide enough producer gas to fire 10 tanks weighing 3 tons each to a temperature of 890 deg. C. from room temperature in about 5 hrs. These data make allowances for heat lost in removing and recharging the ware and it will be obvious that in spite of the large radiating surface the furnace has attained a surprising degree of efficiency.

One unusual feature lies in the method of charging. The furnace chamber is considerably above floor level and the rotatable bottom is raised and lowered by means of a hydraulic ram. The temperature is closely controlled by thermo-couples placed at strategic points in the firing chamber while optical pyrometers, sighted on to the surface of the tank, being annealed or enamelled, indicate when the charge has attained the desired temperature (Figs. 6 and 7). For long it was considered necessary to protect enamelled ware from the effects of furnace gases by using only the muffle type of furnace but the better understanding, which comes from careful investigations, has shown that by controlling the furnace atmosphere and eliminating deleterious gases, it is quite reasonable to process in the reverberatory or direct-fired type. For this reason the management, at Leven, installed an automatic gas recorder which, in graphical form, indicates the concentrations of carbon dioxide, carbon monoxide and free oxygen present in the furnace atmosphere at any given time. The accuracy of this instrument is periodically checked by laboratory analyses.

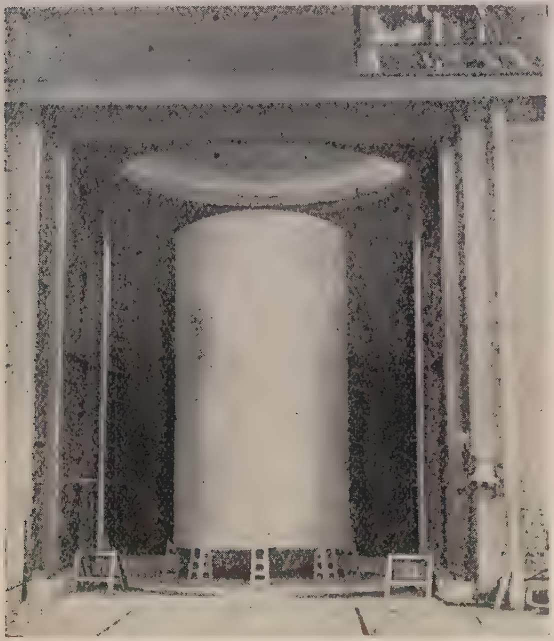

FIG. 6.—REVERBERATORY FURNACE, FLOOR LOWERED.

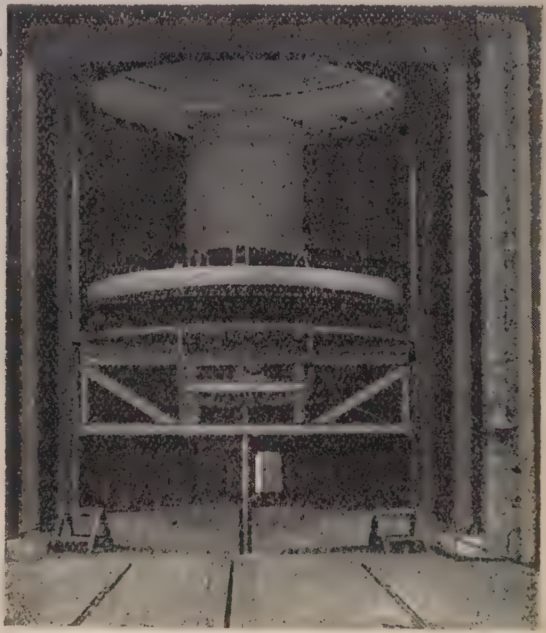

FIG. 7.—REVERBERATORY FURNACE, FLOOR RAISED.

Smaller work, done by the hot-dusting process, obviously demands processing in the muffle type by reason of the intermittent nature of the firing (Fig. 8). Muffle furnaces are most inefficient and wasteful from the heat-transfer point of view. So many heat units are lost in heating firebricks that it is highly important to give due consideration to design, materials and proper insulation when installing this type. As there is little transfer of heat by convection, reliance must be placed solely on radiant heat to fire out the ware, hence the necessity of carefully planning the purchase of refractories.

The thermal conductivity of the muffle floor and walls adjacent to the combustion chamber has an important bearing on fuel costs and general efficiency. So far as modern oil-fired furnaces are concerned it is strongly recommended that silicon carbide bricks be used in these parts. The thermal conductivity of this material is over 100 in the region of 1,000 deg. C., and this is many times greater than that of aluminous firebrick. Its only disadvantage is that it tends to oxidise in the temperature region of 800 to 1,000 deg. C. (due to the opening and shutting of the furnace door repeatedly) and flaking may result.

The intensely hot oil flame gives high combustion chamber temperatures and those parts of the structure which receive direct flame impingement become very hot indeed. While firebricks with a high alumina content are often employed, in personal experience it was found that they did not allow a sufficient margin of safety when used at the high temperatures attained in a modern furnace, and that under severe conditions squatting and spalling occurred in a very short time. A volume-stable, highly refractory material with good thermal conductivity, is surely called for and these desirable qualities are met by fused alumina bricks. The higher initial cost of these materials is always offset by the structural stability and longer life secured. For the sides of the furnace structure where the temperature is lower, aluminous firebricks (50 per cent. Al_2O_3) serve quite well, while for less exposed parts ordinary Scottish firebricks serve the purpose. Often, it proves a wise step to insulate the furnace with a layer of magnesia insulating bricks. A saving of fuel can often be effected by preheating the air supplied to the burners or, as is done in the plant under discussion, using the hot air to dry out the sprayed ware. Pyrometric control is used, as before, to aid the enameller to fire out the vessels. In hot dusting, though, the first prerequisites are good judgment and experience.

Mill Room

When trouble arises in the shops there seems to be a phobia among executives which gives them an urge to trace the illness back to the mills. This attitude is often justified, but the author's firm, believing that prevention is better than cure, insists on a rigid technical control being applied to milling and mixing processes. Mixtures, milling times and temperatures are all closely standardised, which means that routine tests must be carried out on every batch of enamel slip delivered from the mills in order to keep the properties within specified limits. Fineness, water content, specific gravity, mobility and yield value are the constants regularly determined. Of these tests, the first three are commonly carried out in most plants. The fineness is usually determined by screening the slip through graded sieves, and expressing the results as the number of grammes of material retained on a mesh of definite size. The water content can be rapidly gauged on the plant, by carrying out a specific gravity determination on the slip and at the same time knowing, or at least assuming, the value for the gravity of the solids in the enamel.

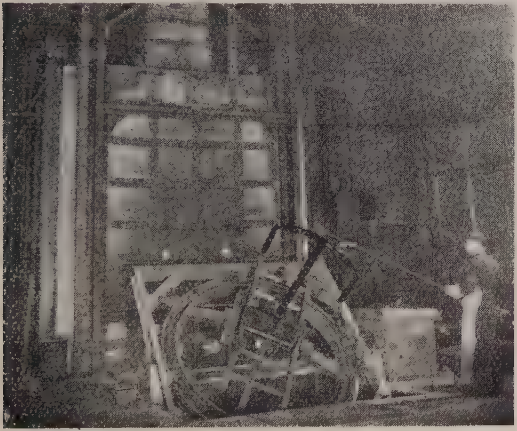

FIG. 8.—MUFFLE FURNACE SHOWING AN ANCHOR-TYPE STIRRER BEING DUSTED.

The flow of matter can be divided into two categories—plastic flow and viscous flow. Viscous flow is the characteristic of a true fluid and viscosity is one of the important constants used in making a comparison of the properties of such fluids. If a cup with an orifice in the bottom is filled with a viscous liquid, the latter will flow through the orifice without regard to the hydrostatic head. On the other hand, a plastic material must have a definite force to start flow by overcoming inertia, and this force is termed the "yield value." The rate of flow which occurs when this value is exceeded is termed the "mobility."

Testing Enamels with the Mobilometer

An enamel slip is a plastic material and is very similar in this respect to a paint. For determining the consistency it will be seen from the foregoing that ordinary viscometers are not suitable for such tests. The simplest and easiest to operate of the instruments for measuring the consistency of plastic materials is the mobilometer. This instrument is particularly suitable for testing enamels, and is shown in the foreground of Fig. 9.

The best procedure is to first obtain a thorough mixture of the slip to be tested, and this can most readily be accomplished by mechanical agitation of the slip in a closed container for a period of 10 min. This period of agitation has a profound effect on the results obtained and must be standardised to get consistent results. The amount of water in the slip likewise has a decided effect on the results obtained, and it is best to control this factor within a narrow range, dependent on the type and working properties of the set-up concerned. After the water content is adjusted and the slip agitated, it can be added to the cylinder of the instrument and the determination proceeded with.

The rate of flow of the plunger falling through this known volume of slip is plotted against the shearing stress causing the flow, and the slope of the curve obtained is a measure of the mobility. The point where the extended curve intercepts the weight axis is taken as the yield value. The time which elapses between successive falls of the stem assembly will usually be found to affect the results, and the writer would advise that the stem and disc be not wiped, but only allowed to drain free of surplus enamel before being immersed for further runs. The thixotropy of the slip is possibly the governing factor in this case. It is very true that the "set" of an enamel drops off very rapidly with increase in temperature. Practical enamellers will agree that on a very hot day in summer the slip will lose "set" and be more difficult to apply. It is unnecessary, of course, to remark on the pronounced effect which variations in the amounts of electrolytes present in the slip have on the mobility. The above factors can readily be tested and investigated by means of the mobilometer. Moreover, the instrument has proved extremely useful in this particular plant for investigational as well as for control work.

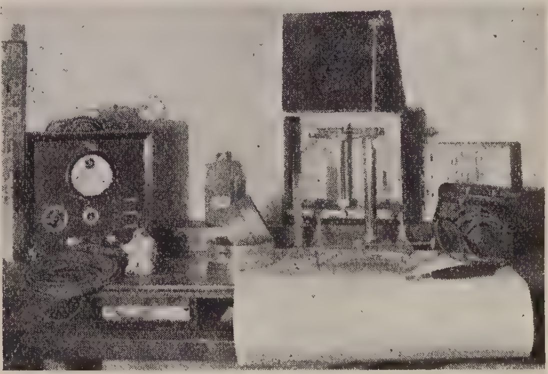

FIG. 9.—TESTING APPARATUS USED ON THE PRODUCTION LINE.

Some useful instruments which are used in the production line and which are indispensable for the maintenance of a Grade 1 throughput are shown in Fig. 9. The magnetic thickness gauge can be of definite advantage. The test does not end with the measurement of depth of enamel layer, but rather with the modifications to technique which the results will surely suggest.

In vessels which have subsequently to withstand chemical attack, small blemishes on the enamel which might tend to expose metal may be disastrous. Indeed, it is advisable to search out such flaws diligently and, at the inspector's discretion, either to repair them or reprocess the entire vessel. For this purpose, both the high-frequency electric spark tester and a low voltage Megger type of tester are used.

The former instrument is used on all vessels processed by the dry or "hot-dust" method. By this means, the mains voltage is stepped up and the actual potential behind the discharge is in the region of 10,000 volts. The unbroken enamel surface is, naturally, a non-conductor, but so soon as the wire coil at the discharge end of the machine is proximate to a flaw, the high electric pressure results in a spark bridging the gap to the metal surface, and so to earth. This instrument is inexpensive and cuts the testing time down to a minimum. The nature of this test precludes the possibility of any serious flaw being overlooked. At one time, the suspicion existed that maybe the application of such high voltages to the enamel layer might fracture even a coating of perfect insulating power. Any years that existed were dispelled by applying the discharge over a single spot on the glass surface for an extended period. In fact, after two transformers had been "burned out," the enamel still withstood any induced stresses.

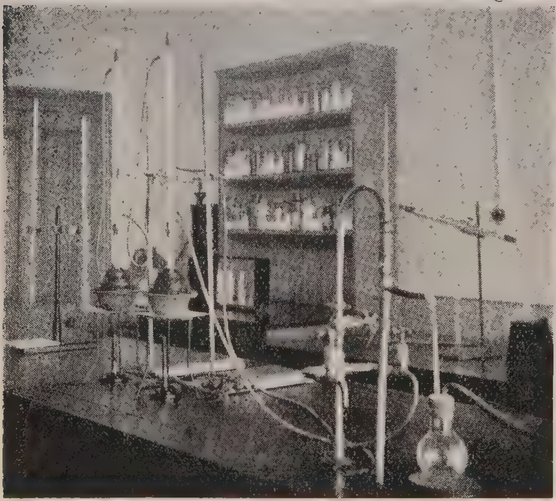

FIG. 10.—LABORATORY ACID-RESISTANCE TEST.

Voltmeter and Milliammeter

This instrument, shown on the left-hand side of Fig. 9, is used on vessels which have been enamelled by the wet or spray method. In principle it is similar to the Megger tester. The surface under test is swabbed with the pad, which is saturated with a 1 per cent. solution, of phenol phthalein. Any pinholes or areas of excessive thinness which give contact and thus complete the electric circuit produce a pink coloration on the pad. Full-scale deflection is obtained on the galvanometer panel, and so soon as contact is made the pointer indicates the presence of a flaw.

The reason for using a low voltage test on sprayed articles is that the presence of clay and electrolytes in the slip renders the fired surface quite permeable to a high voltage discharge.

Laboratory Tests

There are, unfortunately, no standard and strictly comparable methods for testing the more empirical properties of vitreous enamels. Shatter or impact values, acid resistance and resistance to thermal shock—to mention only three—are often matters of pure conjecture, and the values given vary, from plant to plant, with the individual methods of testing used. It is to be hoped that, when industrial life returns to normal, enamellers will make closer co-operation in this matter a part of their post-war plans.

An attempt was made some time ago to evolve a standardised procedure for the testing of acid resistance. This recommended method was issued by the Joint Committee on Vitreous Enamelling of the I.V.E. and B.C.I.R.A., and the details of the method are given in their publication. The most resistant enamel which they figure gave a result of 12 mg. per sq. dm. loss, while a steel enamel of the writer's gave as the loss in weight of 0.5 mg. per sq. dm. A (cast-iron) glass, regularly used in production, gave a loss in weight of 0.7 mg. per sq. dm. when tested with oxalic acid, according to the standard procedure.

It would seem that a shortcoming of this test is that it does not take into account the existence of super-resistant glasses. The point is, that degree of attack is quite considerable in the usual types of enamels, but that in highly resistant glasses the losses are only fractions of a milligram and, in such cases, results are difficult to duplicate. When weighing to such small fractions the personal factor largely influences results and, for comparisons, the difference of one milligram might alter the relative positions in a list of enamels arranged in order of their resistance to attack.

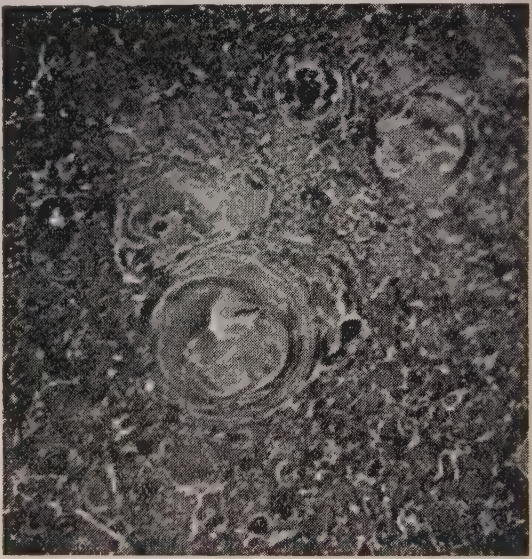

FIG. 11.—ENAMEL SURFACE ETCHED WITH HYDROFLUORIC ACID IN ALCOHOL. (× 500.)

In personal practice a reflux resistivity test is carried out, in which an adaption of the usual Soxhlet extraction apparatus is used. Hydrochloric acid of 20.8 per cent. by weight strength is used, and the test can be conveniently carried out in either the vapour phase or the liquid phase at a standard temperature and time. The powdered fraction which is taken for test is always carefully graded first, and, for the vapour phase test, is suspended in a little container made of platinum gauze. This method ensures that a much greater area of contact is obtained.

The test cup method finds ready application when the behaviour, on these enamels, of an untried chemical needs some investigation. Two enamelled test cups are clamped together, with a suitable gasket between the flanges, as shown on the photograph in Fig. 10. The upper cup has a conveniently shaped hole bored through it in order to make a good connection with the cork of a reflux condenser. Thus, measured amount of the particular " devil's brew " under test may be refluxed within the cup for periods extending, if necessary, into weeks. Quantitative results may be obtained from the measured loss in weight, but, generally speaking, it is sufficient to note the nature and degree of surface attack by means of a suitable magnifying glass.

The method used for testing the adherence of the enamel to the metallic base is, it must be confessed, somewhat empirical. It consists of a frame arrangement, so constructed as to allow a 100 gramme steel ball to fall through a distance of 50 cm. on to the surface being tested. The number of consecutive blows necessary to cause primary flaking is reported as the " impact value." Using the thickness meter as an aid to deducing results, this impact figure is useful in estimating the ability of an enamel to resist shattering.

Fusion Points

The procedure used in these laboratories for determining the fusion points of glasses is that of plotting cooling curves. To do this a platinum-rhodium thermocouple is placed in molten enamel, contained in a crucible, and the temperature plotted against the rate of cooling. The heat of fusion causes a break in the cooling curve from which data can be obtained for determining the fusion temperature. Fusion, of course, usually takes place over a range of temperature, depending on the melting points of the compounds forming the batch. Never does one obtain a perfectly homogeneous melt. Apart from the minute particles of undissolved refractory which may be present more than one phase usually separates from the melt as solidification proceeds. An area of the solid enamel less rich in silica than its surroundings would be preferentially dissolved by acids, and it can be accepted that the lower melting point phases will tend to rise to the surface.

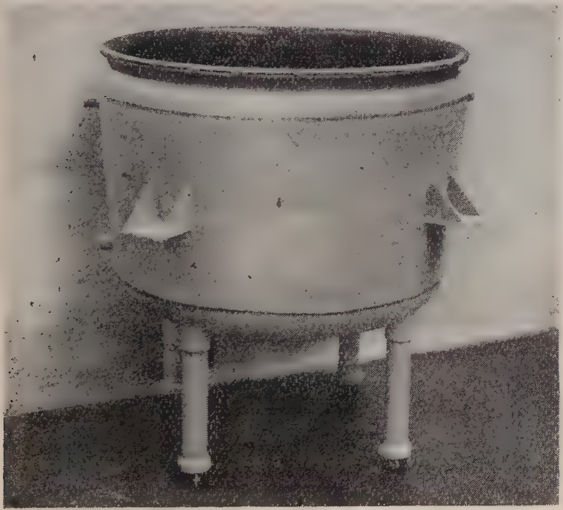

FIG. 12.—BODY OF ENAMELLED REACTION VESSEL.

The microscope is a valuable aid to such studies and the micrograph (Fig. 11) illustrates the above points. The photograph was taken at a magnification of 100 diameters and the surface of the well smelted and fired enamel was etched with a 10 per cent. solution of hydrofluoric acid in alcohol. The acid attack is seen to be preferential, and not uniform, in character and thus gives a " grain " effect. The manner in which the molten enamel heals over gas cavities before solidification is also well shown. Although silicate glasses are, in general, amorphous solid solutions, these facts should be borne in mind when considering resistance to attack by chemicals. *No silicate enamel will resist solution by alkaline liquids and more particularly hot caustic alkalis.*

Certain chemical engineering applications have rendered the ability to resist fatigue under conditions of rapid temperature changes an important property of these enamels. The test is made in the laboratory by heating enamelled specimens to a predetermined high temperature and quenching them in water. This cycle of operations is repeated until there is indication of failure, and the number of successive changes in temperature is regarded as the index of quality. Titanium oxide in an enamel improves this property considerably. In fact, the inclusion of titanium oxide in the ingredients of enamel formulæ represents one of the material advancements of recent years in the manufacture of frits. In addition, this oxide favourably affects the fusibility and the acid resistance of enamels.

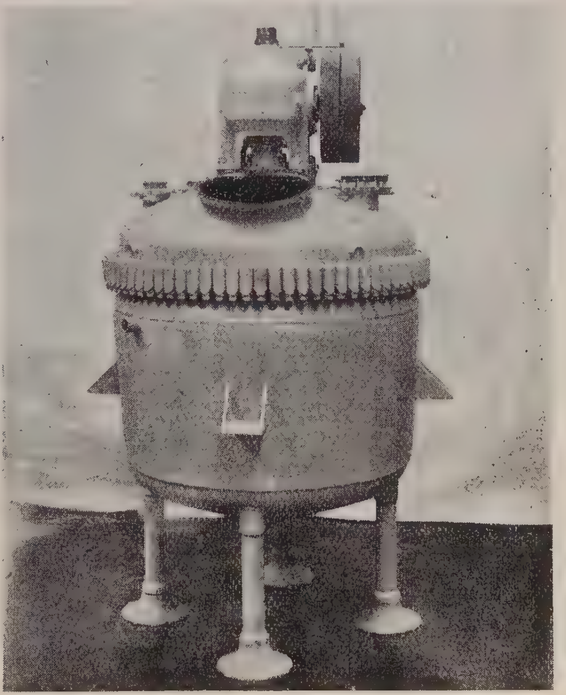

FIG. 13.—ASSEMBLED ENAMELLED REACTION VESSEL.

Other Standard Tests

It is not intended, in this Paper, to review the many standard tests which have been developed by glass technologists, and since applied to ceramic materials. Cubical expansion, thermal conductivity, opacity, gloss, tensile strength and specific heat are all properties of importance, but are well described elsewhere. Fundamental research was early carried out on glass, but the work has since been closely paralleled on vitreous enamels.

The early workers published many worthy contributions of great interest to the searcher after greater chemical resistance in silicate coatings. In personal opinion, the aim should be towards simpler formulæ. The simpler boro-silicates, titanates, zirconates, etc., offer better acid resistance and superior working properties. The chemical composition of these formulæ is much better balanced, with regard to acid and basic radicals, than that of the older and more complex mixtures. The immediate result is the attainment of a more neutral glass with, obviously, more resistant properties. The acid radical part of the composition has a profound effect on both the fusion range of a glass and its acid resistance.

EXAMPLES OF STEEL ENAMELLED EQUIPMENT

The photographs of enamelled chemical equipment shown in Figs. 12 to 15 will interest enamellers and, at the same time, give the engineers food for thought. The line of completed milk storage vessels, shown in Fig. 16 as awaiting shipment, is somewhat reminiscent of things past, but holds, for the enamelling industry, the promise of happier days to come.

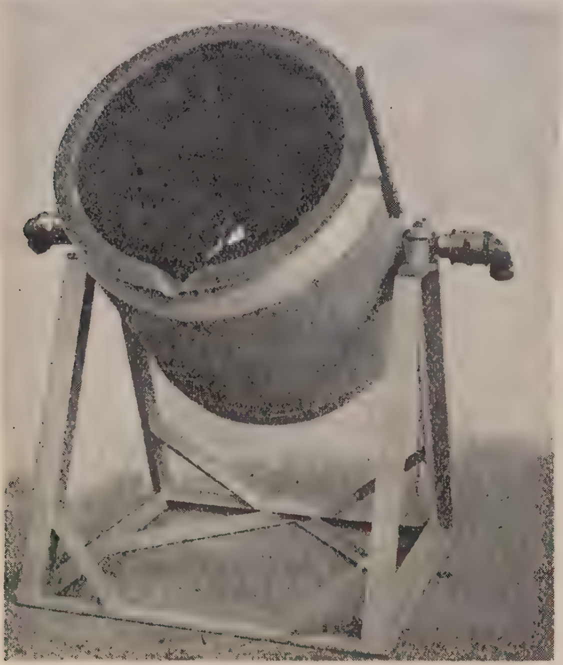

FIG. 14.—POURING VESSEL FOR CHEMICALS.

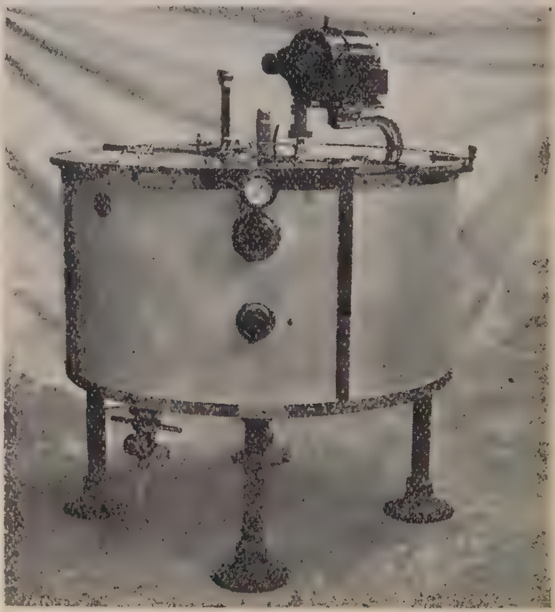

FIG. 15.—TYPICAL SMALL FINISHED VESSEL WITH FITTINGS.

The agitator or stirrer shown in Fig. 17, whether it be made in cast iron or steel, constitutes a tricky enamelling proposition. The design needs careful consideration, as the blade-tips, acting in a manner similar to radiator fins, pick up and lose heat at a faster rate than does the stock.

In order to obtain otherwise unobtainable data on the behaviour of the enamel layer when subjected to excessive stresses in practice, a full-scale plant test was conducted as follows:—Ever-increasing steam pressure was applied to the jacket of an enamelled reaction vessel and the behaviour of the glass under the stresses imposed by the steadily expanding base metal was closely observed. The shell was tested to destruction and the interesting point lies in the fact that the enamel layer did not begin its initial flaking (at the radii) until 85 per cent. of the total pressure had been applied. Although considerable yield must have taken place in the steel at lower pressures, it does seem astonishing that no flaking took place in the lining till a jacket pressure of 475 lbs. per sq. in. had been reached. The enamel fracture shown on the right of Fig. 18 is worthy of study, as the adhering glass takes a pattern peculiar to such compressional failures.

The Glass Lining of Cast Iron

The application of resistant silicate coatings to iron castings is more difficult and sometimes more hazardous than the processing of mild steel. It offers more scope for individual research and probably, for this reason, has a greater appeal for the enamel technologist. The composition of the enamels requires modification to accommodate them to the characteristics of cast iron while the technique of application must be varied to suit this alternative base metal. In the field of acid-resisting enamelled chemical equipment, cast iron offers attractive possibilities. The cheapness associated with the manufacturing methods used in the production of iron castings of a repetition and standard nature is, in itself, a recommendation. The limiting factors are, naturally, design and size. The author has continually advocated the use of, and tried to develop, glass-lined cast-iron fittings for chemical equipment, such as pipes, flanges, valves, stills, evaporators, and reaction pots.

The fundamental difficulty lies in the fact that these silicate glasses, which are, of course, true enamels, have a much higher fusion range and are more refractory than the general run of enamels used in the light-castings enamelling section of the industry. It must be understood, however, that by and large, the methods of applying and processing these coatings conform to the tenets of good enamelling practice wherever carried out. The dry dust method is of greater applicability, but the wet process is also used on occasions.

An idea will be obtained, from the photographs, of some of the regular applications of silicate coatings to iron castings. Fig. 19 shows a wet-sprayed chemical pot with a bottom outlet. The cover shown in Fig. 20 is about 5 ft. dia., ¾ in. thick and has openings for a man-hole, a thermo-pocket and branch connections. This is a hot-dusted job.

Fig. 21 includes a well-known type of valve which is regularly enamelled and a cast-iron stirrer. A cast-iron enamelled pipeline assembly is shown in Fig. 22, with a reducer bend and T-piece clamped together. It may be stated that when these silicate-lined castings are commissioned they are called upon to withstand extremely corrosive conditions (as for example nitric acid and even chlorine gas in the presence of wet hydrochloric acid) and stand up well to the service.

Foundry Practice and Composition of Iron

The genesis of the entire process lies in the cupola and in the proper selection of melting stock. No additional precautions are necessary, over and above the ordinary sensible care taken in the average foundry, to obtain clean, hot and unoxidised metal. If those conditions prevail there is no need to employ special fluxes and ladle dopes as is sometimes advocated.

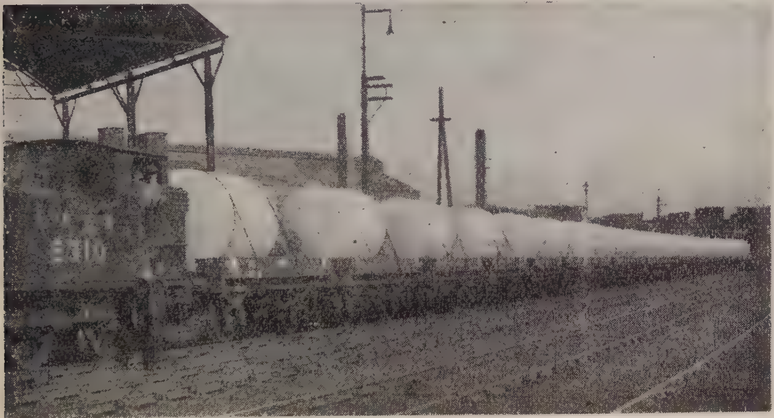

FIG. 16.—GLASS-LINED VESSELS READY FOR DESPATCH.

Attention paid to moulding details is well worth while; sand practice is often deserving of care and a review of gating methods will pay a dividend at a later stage if good clean castings with favourable surfaces be the accepted criteria of good enamelling stock. Gates should never be dropped directly on to the cores or moulds, if at all avoidable, as this often results in loose sand being carried into the casting by the primary stream of metal. The ideal method of using cut gates with shrink bobs or dirt traps should be used where possible. The temptation to sleek the moulds and cores with plumbago should be stoutly resisted, for the number of subcutaneous blowholes in the resulting castings will be directly proportional to the amount of facings used. A light dust with a mixture of plumbago and talc will be sufficient to prevent the sand from burning in, and in the case of dry or oil sand cores, personal practice is to apply a thin wash of the following composition: 4 lbs. plumbago, 4 lbs. terra flake, ½ lb. "treacle," 3 galls. water.

The chemical composition of the base metal is really of only secondary importance. Although it may seem rather sweeping it must be asserted that, given a clean casting, the microstructure is the all-important point. Troubles will be halved if the carbides are completely broken down and the graphite is precipitated in as fine a form as is practicable. Although some have claimed that pearlite iron makes the best base for enamel and others have demonstrated that solid graphite may be given a vitreous coating, these results must be regarded as, if not freakish, at least being of limited applicability. The high temperature anneal which is usually given to enamelling castings in order to "burn out" extraneous matter from the iron surfaces has the added effect of causing pearlite breakdown and this, in itself, is worth striving for. It is, naturally, agreed that the attainment of a suitable microstructure is not entirely independent of the chemical analyses. The silicon content, for instance, has a decided influence on the attainment of a fully ferritic matrix after the annealing treatment.

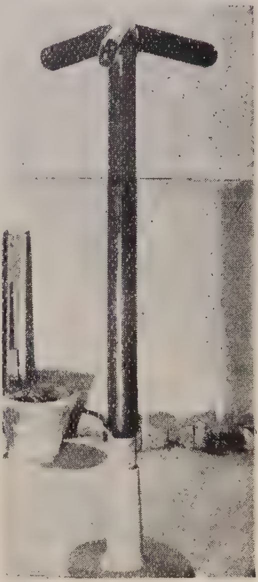

FIG. 17.—ENAMELLED STIRRER.

Copper in Cast-Iron Enamelling Stock

In the beginning, this investigation was undertaken to inquire into the possibilities underlying the use of an engineering grade of iron with regard to vitreous enamelling. In particular, the requirement of the moment was a cast iron which would be tight to a

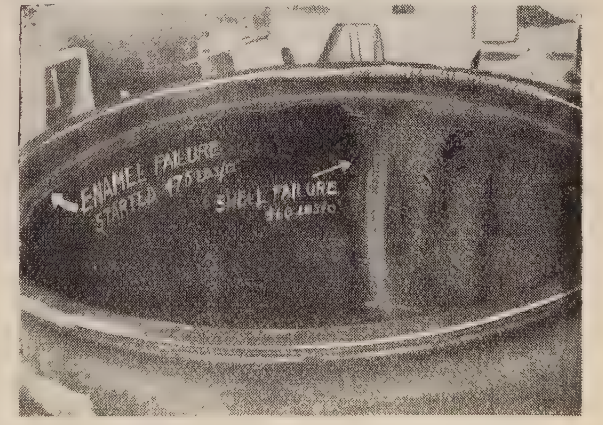

FIG. 18.—SHOWING THE RESULTS OF A FULL-SCALE PRESSURE TEST.

considerable water pressure after processing, *i.e.*, sand-blasting, annealing and enamelling. It was to be used in the production of still castings which, in shape, resembled furnace pans. The inner vessel had to be enamelled in the inside and both the inner and outer jackets had, as is mentioned above, to be pressure tight.

The castings were originally bought from a light castings enamelling firm, and although the enamelling properties were fairly good, they were quite porous to water under pressure. The analysis of this iron is compared below with that of an average general engineering type of casting

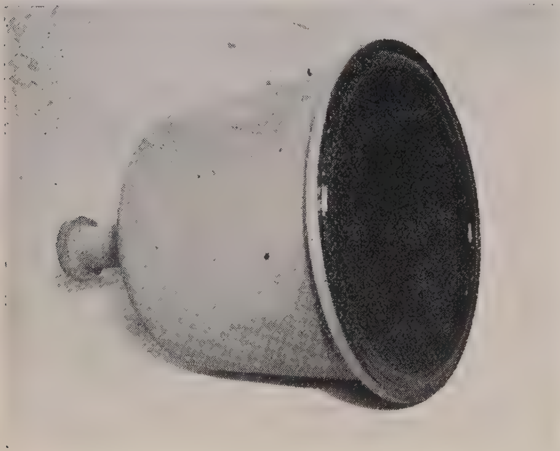

FIG. 19.—GLASS-LINED CAST-IRON CHEMICAL POT.

	High Phosphoric Iron Per cent	General Engineering Iron Per cent
T.C ..	3.20	3.00—3.30
Si ..	2.49	1.80—2.00
Mn ..	0.49	0.60—0.80
S ..	0.067	*circa* 0.070
P ..	1.25	0.40—0.50

The difference in the silicon and phosphorus figures will be noted. The phosphorus content is too high, in the first instance, for pressure work. The enamelling potentialities of the engineering class of iron were tried out by casting test cups the same shape and section ($\frac{3}{8}$ in.) as the stills. All these test castings were given a pressure test before enamelling and were perfectly tight up to 100 lbs. per sq. in. A dozen of these were then annealed at the enamelling temperature for a period of time equal to that of ordinary firing practice and on repeating the pressure test all leaked badly at 60 lbs. per sq. in. The reason for this is that, on annealing the castings, the graphite plates which are relatively thick and coarse become more or less oxidised at the surface, while the growth and cracking which take place along the graphite planes break up the continuity of the metal.

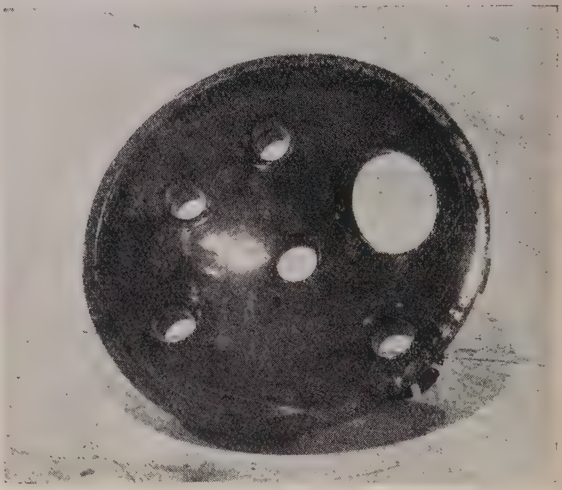

FIG. 20.—ENAMELLED CAST-IRON REACTION VESSEL COVER.

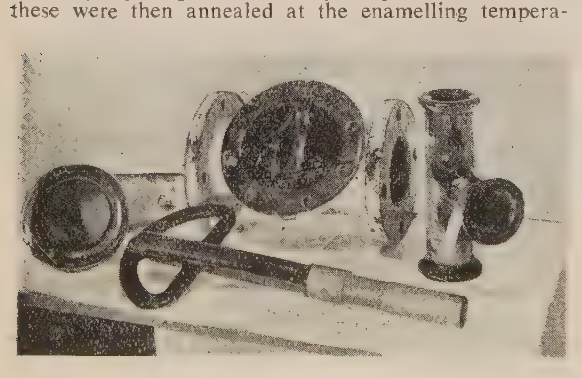

FIG. 21.—CAST-IRON VALVE, STIRRER AND PIPES, LINED WITH ACID-RESISTING GLASS.

It follows that the graphite refinement associated with the use of alloys might offer a solution. A 1 per cent. addition of nickel was tried with perfectly satisfactory results. The test cups were enamelled with a good finish and were pressure tight. It may be recorded that a batch of cups which had an accidental surface chill gave very little enamel adhesion.

A few deductions concerning the enamelling of engineering irons can be made from the above findings.

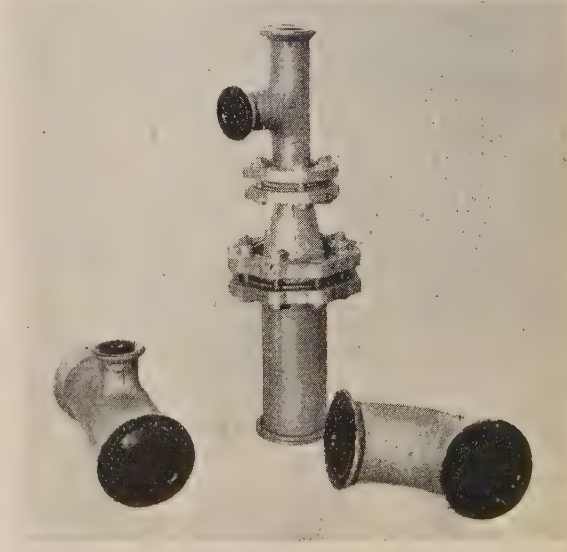

FIG. 22.—ASSEMBLED ENAMELLED PIPE, REDUCER AND TEE-PIECE.

First, a fine graphite structure is advantageous. Secondly, the more graphitisation has progressed (pearlitic breakdown) before enamelling the better. In a light casting this is attained by higher percentages of silicon and phosphorus being present, and free ferrite is nearly always evident in the microstructure of such an iron. In engineering irons the graphitising effect and refining action of certain alloys might be beneficial.

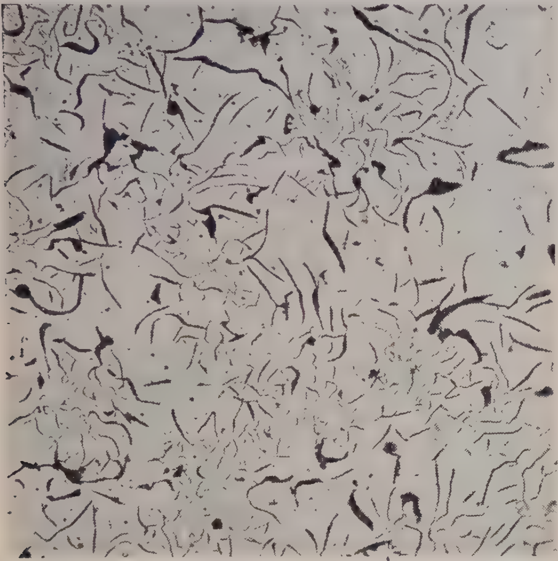

Fig. 22a.—Micrograph of Ordinary Engineering Type of Cast-Iron held at 850 deg. C. for 30 mins. Unetched (× 100). With Large Graphite Flakes.

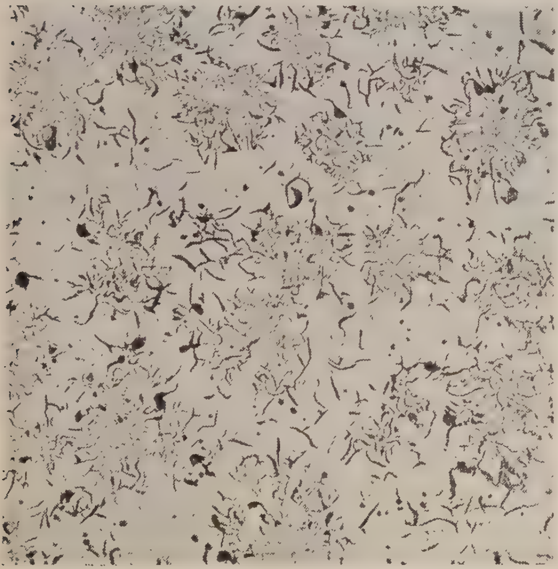

Fig. 23a.—Micrograph of Copper-bearing Cast Iron held at 850 deg. C. for 30 mins. Unetched (× 100). Fine Graphite Flakes and Signs of Supercooling.

Experiments with Copper

The use of copper in this respect suggested possibilities. At the time of the investigation it was plentiful and it was cheap. It could be conveniently alloyed with cast iron and for all the following tests the copper was added, in the form of clean scrap clippings, to hand ladles prior to filling at the cupola spout.

Commercial cast iron can dissolve about 6 per cent.

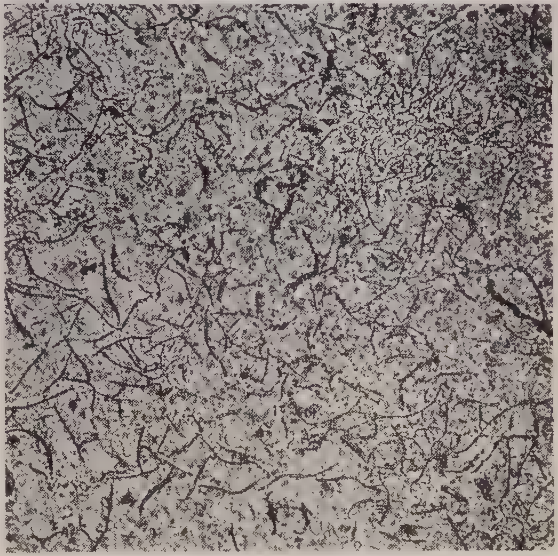

Fig. 22b.—Micrograph of Ordinary Engineering Type of Cast Iron held at 850 deg. C. for 30 mins. Etched with 4 per cent. Picric Acid (× 100). Much Pearlite shown.

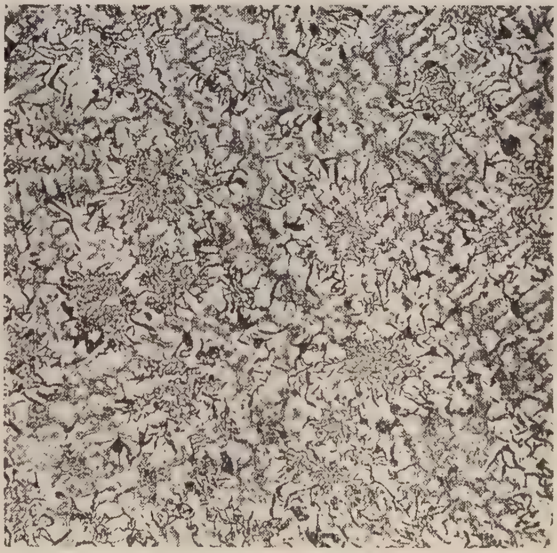

Fig. 23b.—Micrograph of Copper-bearing Cast Iron held at 850 deg. C. for 30 mins. Etched with 4 per cent. Picric Acid (× 100). Pearlite Breakdown nearly complete.

of copper when molten and the amount present in excess of this quantity solidifies in the form of copper-rich globules, which are termed primary copper. As the temperature falls to 750 deg. C., so does the solid solubility in gamma iron decrease till it reaches 3.5 per cent. Of the copper dissolved in gamma iron, only about 1.0 per cent. is soluble in alpha iron (the low-temperature form), and as the temperature decreases through the critical range, any copper in excess of this amount is precipitated as secondary copper, which is not resolvable under the microscope unless very high magnifications are used. However, this secondary copper is not revealed by microscopic examination of cast irons containing less than 3.5 per cent. copper; hence this amount has been termed the "apparent" solubility. The real solubility of copper in commercial cast iron probably lies in the region of 1 per cent. or less, depending on the amounts of other elements present.

It is claimed that copper exerts no influence on the breakdown of pearlitic carbide. This is accepted as applying to castings which are fairly rapidly cooled in the moulds, but it is the author's opinion that submicroscopic secondary copper serves as nuclei for the precipitation of graphite from the eutectoid iron carbide, at least on slow cooling and most certainly on annealing. This is the mechanism on which the following tests are based, for it is generally accepted that, in higher pearlitic irons, the breakdown of the carbide plates at enamelling temperatures gives rise to trouble.

Thus, it was considered that the graphitising influence of the copper would facilitate the graphite and ferrite formation at lower temperatures as well as refining the structure with beneficial results in the enamelling shop. There would be no chance of obtaining a chilled surface on thin sections of engineering quality metal, and the fluidity of these low-phosphorus irons would, if anything, be improved by copper additions.

K. Emmel (Giesserei, 1939, **26,** 285-287) stated that enamel adherence on surfaces of ferritic iron, even when highly graphitised, was very good, but he found that practically no adherence was obtained on fully pearlitic irons. This latter structure is typical of engineering irons in the as-cast condition, and thus the aforementioned tendency of copper to promote the formation of ferrite and fine graphite would be a decided advantage.

Observations on Test Plates

Eight series of test plates were cast in green-sand moulds with metal of substantially similar composition, but to each series of at least a dozen plates was added an increasing increment of copper. Thus, Series A contained no copper; Series B, 0.55 per cent.; Series C, 1.12 per cent.; Series D, 1.51 per cent.; Series E, 2.20 per cent.; Series F, 3.05 per cent.; Series G, 4.10 per cent.; Series H, 5.20 per cent.; and Series J, 6.00 per cent. There was a slight variation in the analyses of the higher copper groups, due to a dilution effect.

The composition of the base iron was as follows:—T.C, 3.25; Gr, 2.55; C.C, 0.70; Si, 1.95; Mn, 0.75; S, 0.076, and P, 0.44 per cent. In accordance with convention the plates were all given a preliminary anneal under conditions of standard time and temperature. After sand-blasting they received a ground-coat. The cover-coats were fired on by the hot dust method at 800 deg. C.

The plates containing the higher percentages of copper need not be considered because, as was expected, the primary copper tended to coalesce at the firing temperature, and resulted in no surface adhesion when the enamel was applied. The unalloyed base iron plates gave erratic results and showed a distinct tendency to produce pin-holing and blistering defects. In short, the plates containing between 1 and 2 per cent. of copper enamelled perfectly with a flawless finish and a stronger grip. Under repeated impact, the enamels fired on to the copper-irons gave better adhesion values and showed less tendency for the ground-coats to strip than did the plain-iron enamels.

A number of similar plates were studied microscopically to determine the effects of copper on the annealing times necessary to complete pearlite breakdown, and also to note the effect of this alloy on the graphite structure. Representative micrographs are shown in Figs. 22a to 23b. Figs. 22a and 22b show the unetched and etched structures, respectively, of an unalloyed iron to the analysis given above, while the same base iron with 1.50 per cent. of copper is shown in the unetched and etched conditions in Figs. 23a and 23b. Both irons were annealed for 30 mins. in the same furnace at 830 deg. C. The notable points are: (1) Decomposition of the pearlite is practically complete in the case of the copper iron, while it has not progressed very far in the unalloyed metal. (2) The graphite in the alloyed iron is much finer in form and tends towards a supercooled structure. The indications are that graphite of this form is less liable to oxidation in the enamelling furnace.

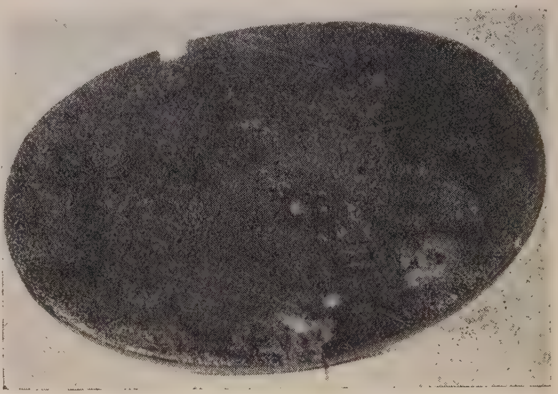

FIG. 24.—ENAMELLED MALLEABLE IRON DOOR SHOWING BAD BLISTERS.

Some doubt has lately been thrown on this graphite-oxidation theory by some able American workers, who postulate that dissolved hydrogen is thrown out of solution, at enamelling temperatures, into the graphite cavities, where a reaction may take place with the formation of a gas of the methane type. Whether one accepts the hydrogen theory as being the genesis of pin-holing in cast-iron enamels or holds to the more classical ideas of the evolution of carbon oxides, it will be accepted that control of graphite size is a step in the right direction.

The "cast-iron" cover shown in Fig. 24 reveals an enamelled surface extremely defaced by pin-hole defects. This was annealed at a high temperature for a considerable length of time, and many attempts to enamel it resulted in failure. Subsequent analysis and micro-examination proved the article to be a black-heart malleable iron casting. The very low carbon and silicon contents suggested that no breakdown of the eutectoid cementite was possible with ordinary shop furnace practice. The micrograph (Fig. 25) bears out this contention. The specimen sectioned through the enamel-metal interface shows a structure of temper carbon nodules in a matrix consisting of ferrite and pearlite.

Such general blistering could not have been caused by gas evolution from the free graphite, because it will be seen that the surface of the casting consists of a layer relatively free from carbon nodules. Pearlite is noticeable in this layer, and this indicates that decarburisation of the surface layer is incomplete. The structure of the metal at the enamel-metal interface is, in effect, that of a 0.67 per cent. carbon steel. The point to notice is that, although this door invariably blistered with high-temperature enamels, it behaved more rationally when low-fusing enamels were fired on. These contradictory phenomena may be theoretically explained by both the hydrogen and the carbon-oxide hypotheses.

Iron carbide will oxidise only in the higher temperature range, and therefore the evolution of carbon monoxide or carbon dioxide could only be expected to occur at elevated temperatures. If hydrogen is the accepted cause, it is difficult to understand why diffusion does not occur at the lower firing temperatures. The hydrogen is not very soluble in ferrite, but is strongly bonded to the iron carbide. It may be that, at the critical point when the pearlitic carbide goes into solution in the austenite, hydrogen is released and diffuses to the surface. Certainly, when it is considered that these castings may have been in contact with damp mill scale and iron oxide during the annealing cycle, hydrogen must remain suspect.*

Recent experiments on austenitic steels of the 18:8 type showed that when enamel was fired on at temperatures above the critical annealing range (when all the carbides are in solution), it fired down very successfully. When furnaced within the temperature range which results in the precipitation of carbides and the accompanying intergranular corrosion, this material gave rise to delayed popping or fish-scaling. Below each scale was a minute gas hole, indicating that gas had been evolved during firing, but that the pressure had been insufficient to break the enamel surface. From the delayed action effect it would appear that gas was still being evolved after the metal had cooled, and that the pressure set up had eventually blown the enamel off. At the higher temperature firing, the hydrogen was probably released when the carbides went into solution in the austenite and escaped through the fluid enamel. Although these deductions fit in with the hydrogen theory, quite a few things are taken for granted.

Effect of Copper-containing Irons on Adherence

From the author's tests on the adherence of silicate coatings to copper-containing cast irons the following ideas emerge. A thin film of copper oxide probably forms on the surface of the iron, protecting it from excessive oxidation and affording the enamel better grip. It is well known that metallic cobalt, under certain circumstances, plates out of the enamels containing the oxide, and that the electro-deposited coating of cobalt on iron produces better adherence. Amberg, Prior and Richmond (THE FOUNDRY TRADE JOURNAL, Vol. 57, 1094) found that, by electro-depositing a film of molybdenum hydroxide on steel, better adherence was obtained. They stated that a suitable metal should have at least some of the properties of cobalt. It should be in such a position in the electromotive series that iron will replace it in solution; it should have more than one valency; it should have a melting point above the firing temperature of the enamel. Copper is favourably placed with regard to these requirements. Their experiments were conducted using molybdenum oxide to obtain the necessary amount and kind of oxide film on the iron surface to promote adherence.

Copper, slightly in excess of the solubility limit in cast iron, gives just this very thin film of copper oxide which, as well as protecting the iron surface from excessive oxidation gives better "wetting" of the metal surface and hence superior adhesion. The submicroscopic suspension which is dispersed through the metal, in addition to the amount in true solution, adds to this effect. Thus, when castings are heated in air at the normal firing temperatures a measure of protection is afforded.

In the tests under consideration, the ordinary iron plates showed a distinct tendency to oxide and scale formation, while those containing copper remained bright and comparatively scale-free even after prolonged annealing. It seems that if the iron oxide layer is too thick the enamel is incapable of dissolving it and thoroughly wetting the iron, and that the copper addition appears to exercise the necessary control over the oxide formation.

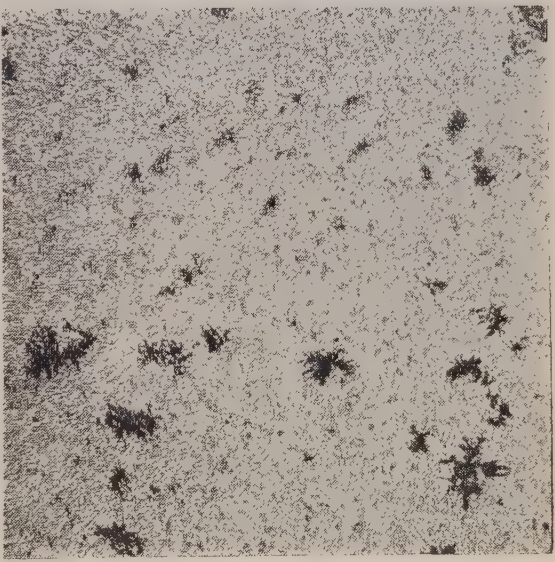

FIG. 25.—MICROGRAPH OF MALLEABLE CAST IRON (SHOWN IN FIG. 24), ETCHED WITH 4 PER CENT. PICRIC ACID IN ALCOHOL (× 60). CONSIDERABLE PEARLITE PRESENT.

Recapitulating, the following are the advantages which these tests indicate will accrue from the use of copper in engineering quality cast iron for enamelling.

(1) The fluidity of the metal is increased and hence the lack of phosphorus is partly counterbalanced by copper additions and the mould impression more clearly delineated in castings of intricate section.

(2) A refinement of the graphite structure gives pressure tightness and inhibits gas formation during firing, as, by virtue of the smaller graphite flakes, less oxidation and formation of the debatable oxides of carbon can take place at the enamel-metal interface.

(3) The eutectoid point occurs at a lower temperature when copper is present in cast iron and shorter annealing times are necessary to complete the carbide breakdown.

(4) The copper oxide skin controls the degree of surface oxidation of the iron at, and under, firing temperatures and gives a stronger grip to the ground coat.

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* The Author has inadvertently referred to the whiteheart process—Editor.

The above notes and related deductions apply, for the most part, only to the enamelling of a general engineering type of cast iron. Certain of the findings, however, might be of general interest to the light-castings enamellers, who, at a future and more propitious time, might be inclined to investigate them further.

Conclusion

A great amount of fundamental research is necessary before cast iron can be fully developed as a base for resistant silicate coatings. Doubtless, new methods such as X-ray diffraction analysis and new tools such as the electron microscope will, some day, elucidate many debatable ceramic questions. An attempt has been made in this Paper to emphasise the importance of chemically-resistant enamels as applied to mild steel and cast iron, and to draw attention to the technical control necessary for their production. The potentialities of these glass coatings and linings, for the future, need no stressing. Millions of pounds sterling are lost each year due to the ravages of corrosion and one of the durable protections of cast-iron and steel structures is a coating of fused silicate glass.

While, in many cases, cast-iron enamellers have gone into temporary eclipse, there may be a small degree of comfort to the industry in the knowledge that at least one section is contributing handsomely to the total war effort.

The writer's thanks are due to Mr. William L. Burns, managing director of Enamelled Metal Products Corporation (1933), Limited, for permission to publish the preceding notes; to Mr. Lindsay Burns, general manager, and to the staff for their much-appreciated co-operation.

DISCUSSION

Mr. J. A. Donaldson asked whether Armco iron had been tried for the vessels illustrated or, alternatively, material of a similar kind. Further, he would appreciate any information available as to the possible decrease in heat conductivity of carborundum bricks after use in the muffle furnace.

In reply, **Mr. Montgomery** said that he had not found it feasible to use Armco iron over a certain gauge; hence mild steel had been found to be cheaper and could be obtained in the heavier gauges required. In the case of special welds, particular attention was paid to the carbon content. He had not found any decrease in heat conductivity of the carborundum bricks. In the normal practice, there were very few drafts present in the muffles discussed, and failure of the carborundum lining was usually due to the general collapse of the wall.

Mr. Biddulph asked whether, in the reflux resistivity test, the article tested is a particle of frit, or an actual part of an enamelled surface. Further, was the etched surface mentioned, frit or enamelled surface? He likewise expressed interest in the plotting of cooling curves. Would Mr. Montgomery enlighten him as to the range of fusion temperatures?

Mr. Montgomery replied that the test mentioned used powdered and graded frit, thus giving maximum surface contact. In the test-cup method, where the liquid was boiled for a lengthy period, use was made of a part of the enamelled surface. For the etched surface illustrations, the finished enamel, after fusing to the metal surface, was used, the etching agent being 20 per cent. HF in alcohol at room temperature. The range of fusion temperatures varied greatly, high Pb enamels having a low range, say 500 to 600 deg. C., while the high-silica glasses would be round about 900 deg. C.

Mr. E. Currie asked whether Mr. Montgomery thought it feasible that, using cast iron, pressures up to, say, 100 lbs. per sq. in. could be an economic proposition.

The **Lecturer** said he thought it was quite feasible, and mentioned how the enamel layer helped pressure tightness.

Replying to Mr. R. R. Shaw as to whether there was any excuse for non-acid-resisting enamels, **Mr. Montgomery** said it was all a question of the different types of acid resistance looked for in industry. For example, the acid resistance aimed at by him would not be generally useful for, say, cooking utensils, etc.

Scottish Branch. **Paper No. 781.**

Aero-Engine Castings*

The Production of Light Alloy Castings for the Rolls Royce Merlin Engine

By JOHN VICKERS, (Member) and B. MacDOUGALL, (Associate Member)

The foundry building of this particular works covers an area of approximately three acres, and finds employment for over 2,000 people, working two shifts. The conditions for the workpeople are the best that could possibly be desired; canteens are provided as part of the foundry building. The lighting, which is of the highest order, consists of a balanced system of standard and mercury vapour lighting, which is particularly effective. Heating is by means of unit heaters at intervals in the roof of the foundry. The ventilating system deals with 130,000 cub. ft. of air per min. from the building, and renders the atmosphere fresh and clear during the whole of the working day. The building is wired throughout with loud-speaker units over which are relayed musical programmes.

PATTERNSHOP AND FOUNDRY TOOL ROOM

The manufacture and maintenance of the pattern equipment, gravity and pressure dies, jigs, fixtures and gauges for a mechanised foundry is essentially of the utmost importance. Thus when the largest mechanised light alloy foundry in the country was planned for the manufacture of castings for the Merlin engine, very special attention was justifiably paid to the patternshop and foundry tool room to ensure that above all, the equipment installed left nothing to be desired from the point of view of general utility relative to the problem to be tackled. Secondly, steps were taken to ensure that the skilled labour employed in these sections should have the opportunity of a specialised training on aero-engine work with the best and latest equipment available.

In the early stages of development of the foundry, local patternmakers were drafted to Coventry, always regarded as the home of the internal combustion engine industry, for a training period on wood and metal patternmaking alongside experts; these trained men then formed the nucleus around which the present department was built up. When it is realised that the foundry under review employs only 30 per cent. of skilled labour on production and that more than 50 per cent. of the unskilled labour is female, it will be appreciated that the ingenuity of the patternmaker is often taxed to the limit to provide patterns and coreboxes requiring the minimum of skill to manipulate. A typical example of this is shown in the sketch of a pattern plate (Fig. 1) for the induction manifold—moulding two castings at one operation and incorporating a mechanism for withdrawing simultaneously ten inclined bosses into the pattern, thereby eliminating the necessity for outside "cover cores" and producing a cleaner and more accurate casting with less risk of scrap due to misplaced cores. The same principle is illustrated in Fig. 2, where four bosses on the cylinder block pattern have been withdrawn from the mould.

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* Mr. Vickers was awarded a Diploma in respect of this Paper. Mr. MacDougall was a Diploma-holder. The authors are respectively Foundry Manager and Assistant Foundry Manager, at a foundry of Rolls Royce Limited.

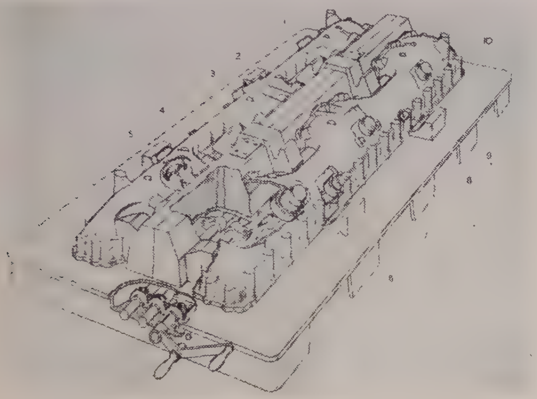

FIG. 1.—SKETCH OF MERLIN XX INDUCTION MANIFOLD PATTERN IN PART SECTION.

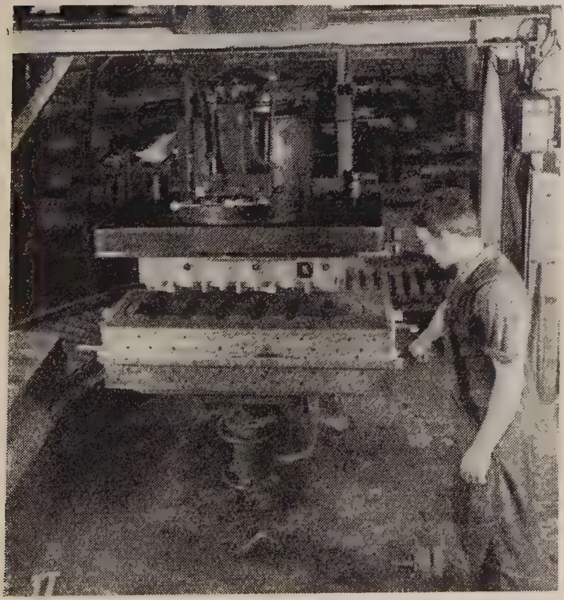

FIG. 2.—MERLIN XX CYLINDER BLOCK MOULDING MACHINE.

Pattern and Corebox Materials

Various materials are used in connection with the manufacture of the pattern and dies according to the particular service required for the part. For example, the pattern shown in Fig. 3 for the upper half crankcase is a "composite" build-up of hardwood and light alloy, with certain of the hard-wearing inserts in steel. The majority of the remaining patterns are made as light-alloy castings with steel or phosphor-bronze inserts "cast" in position wherever possible on the wearing surfaces.

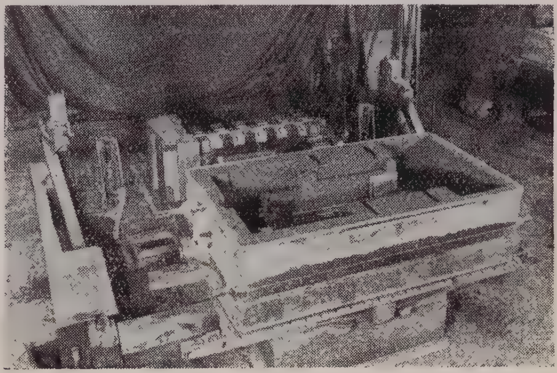

FIG. 3.—MERLIN XX UPPER HALF CRANKCASE MOULDING MACHINE.

Cast iron is frequently resorted to for coreboxes where the weight factor for female coremakers per-

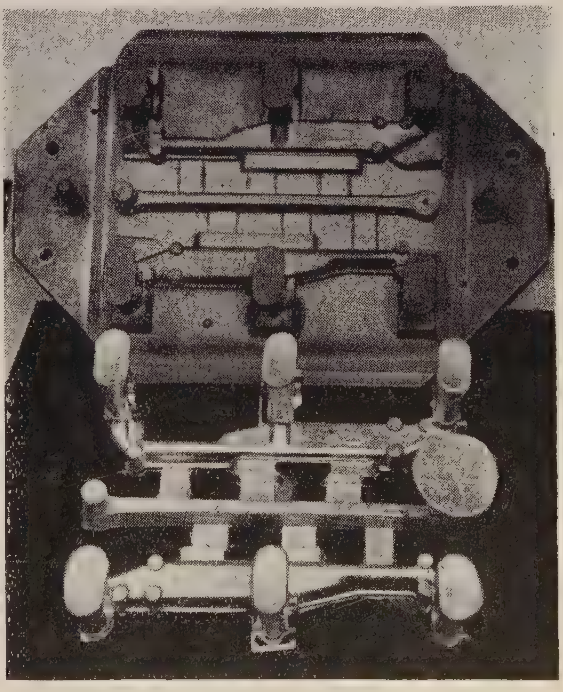

FIG. 4.—PATTERN PLATE WITH GATING SYSTEM INCORPORATED AND SAMPLE CASTING OF CONTROL BRACKET.

mits or can be overcome by mechanical means, particularly in those cases such as the exhaust port cores on the cylinder block which have to be reproduced 12 times per engine. These cast-iron coreboxes stand up to the production of 80,000 to 100,000 cores before any appreciable wear is found to have taken place. Other materials in common use, in most cases in intermediary stages, are plaster of paris, stone, a lead-tin alloy, and dental wax.

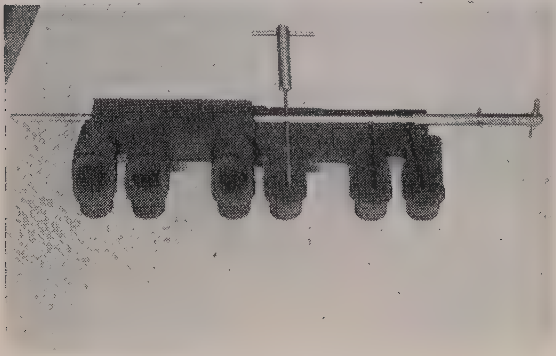

FIG. 5.—GALLERY VENTING SYSTEM ON CYLINDER BLOCK INLET PORT CORE.

Gating and Venting Systems Standardised

All gating systems used in the foundry are incorporated on the pattern equipment, a typical example of which is shown in Fig. 4, thereby eliminating these variables which must inevitably creep in were the moulders allowed to cut their own gating systems in the mould. Fig. 5 shows a typical gallery venting system used in the inlet port core for the cylinder block, the steel rod which forms the gallery vent from end to end of the core giving location to the vent rods inserted into each leg of the exhaust port. After each of these rods has been inserted and withdrawn in the rammed core, the gallery rods are turned through 90 deg., and the vent hole formed in the portions between the gallery rod and the outer face of the core is then filled in. By this means, an excellent artificial vent into each leg of the core with only one outlet from the core itself is formed. This policy of incorporating the details of foundry technique in the pattern equipment is considered to be of prime importance in the maintenance of satisfactory results in the foundry, and doubtless contributes largely to the remarkably low production "cycle" times which have been achieved.

Reproduction from Master Patterns

Obviously, quantity production foundry methods frequently call for more than one set of patterns to be in work at one time. On the cylinder block, for example, there are always at least four patterns in production, each of which incorporates the use of 48 separate sand cores. It will be appreciated, therefore, that in the early planning of the patternshop, it was obvious that provision must be made for the accurate duplication of production pattern equipment, which must essentially be interchangeable to minimise foundry production hold-up due to maintenance work on any individual item. This accurate duplication to extremely fine limits of equipment is facilitated by the use of a Pratt & Whitney fully automatic 3-spindle Keller duplicator and Gorton milling machine with duplicating table.

The Keller duplicator, when reproducing a supercharger casing pattern in aluminium alloy from the original wood pattern, required approximately 150 hrs., which represents a very considerable saving of time over the best alternative method.

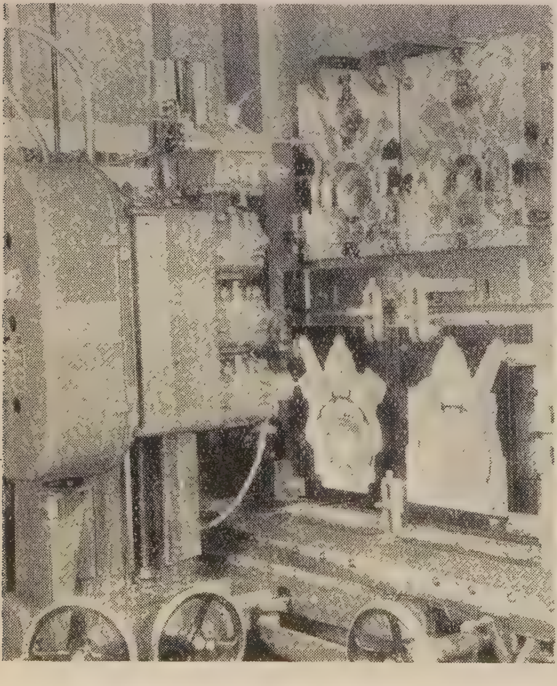

FIG. 6.—KELLER MACHINE WITH TYPICAL COMPLICATED DIE.

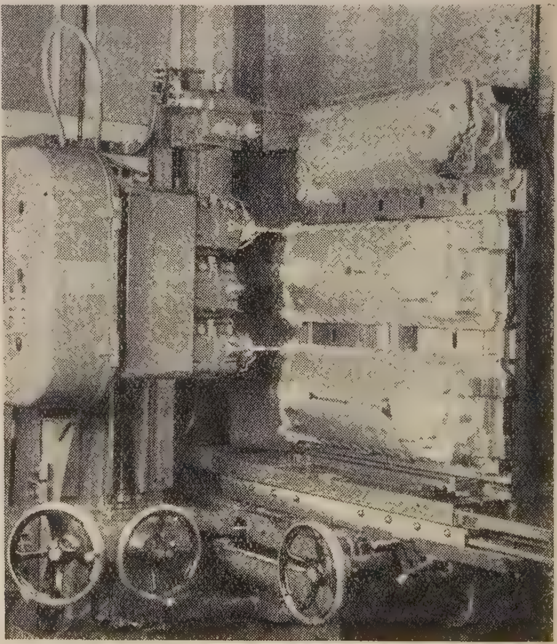

FIG. 7.—KELLER MACHINE WITH MERLIN XX CRANKCASE PATTERN.

The duplicating of an induction manifold pattern on the Gorton milling machine equipped with a duplicating table, though not fully automatic and therefore calling for a certain skill on the part of the operator, introduces a material advantage in speeding up the accurate duplication of patterns.

Two further typical examples of duplication of pattern equipment being carried out on the Keller duplicator are shown in Figs. 6 and 7. Fig. 6 shows the duplication of a breather corebox for the Merlin XX upper half crankcase, whilst Fig. 7 shows the reproduction of two lower half crankcase metal patterns simultaneously from an already proved master pattern. Obviously, these accurately reproduced patterns can be released for production to the foundry with the minimum of delay for "proofing," since the model from which they are reproduced to very fine limits has already passed the necessary proof inspection.

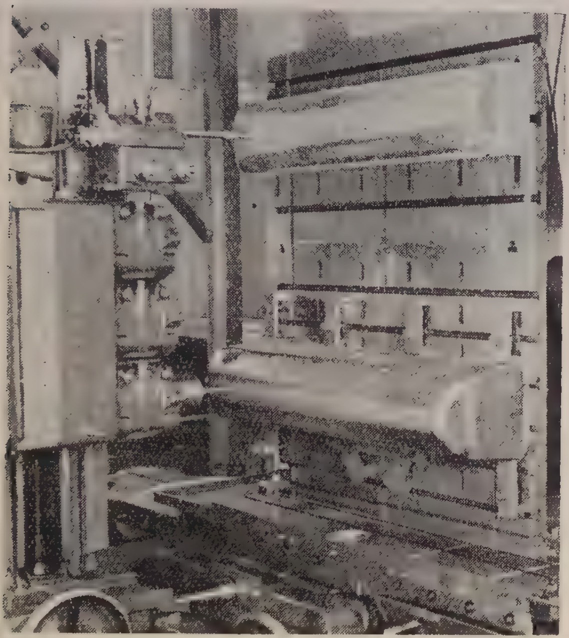

FIG. 8.—KELLER MACHINE WITH MERLIN XX ROCKER COVER CORE.

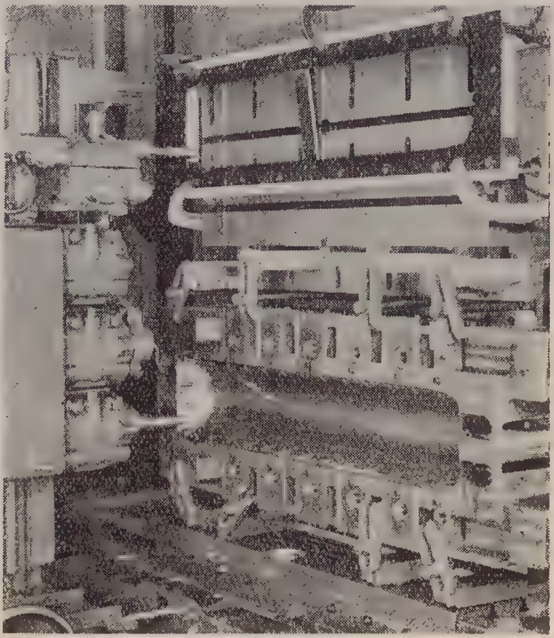

FIG. 9.—KELLER MACHINE WITH MERLIN XX ROCKER COVER DIE.

Figs. 8 and 9 are particularly interesting examples of the adaptation of the Keller duplicator to foundry problems, the parts being reproduced in this case are the top and bottom die blocks, after completion, in work in Fig. 10. In the case of Fig. 8 the model is hardwood block shaped accurately to the desired shape of the top core for the die. After reproducing this top core on the cast-iron die block, a plaster of paris cast is taken from the model of the top block and this plaster case is used in turn as the model in Fig. 9. The cutter used on the cast-iron die block in Fig. 9 is, of course, larger than the tracer head by the desired metal thickness of the casting to be produced from the finished die.

The fact that patternmakers' contraction, or shrinkage, allowances on patterns vary according to the size, design, material and casting temperature of the ultimate casting is well known. For example, certain engine castings in the alloy used are worked to 1/96 contraction, whilst others in the same alloy are made to 1/77 contraction. Then again, certain of the aluminium and silicon bronzes require pattern contraction allowances of as high as 1/48. This variation of contraction allowances on patterns normally debars from the patternmaker the use of fine measuring instruments, such as the Vernier height gauge, micrometer, etc. This difficulty has been overcome in the department under review, all dimensions being issued from the foundry drawing office to include the contraction allowances, so that the patternmaker has the full advantage of the fine measuring instruments of the engineering world.

Chills and Core Carriers

The whole of the chills required in the foundry are produced and fitted to master models in the patternshop before release. Large quantities of these are required and a system of identification has been instituted to render their ready return to the starting point easy. Fig. 11 shows a typical arrangement of chills, mainly produced in cast iron for the face of the wheelcase casting. Each chill carries a series of code letters indicating clearly to the sorter whether the chill is required for a core or mould, the engine part on which used and the position on the pattern or corebox.

Core carriers are also produced in the patternshop in large quantities. These are, undoubtedly, an important contributory factor to the successful use of female unskilled and semi-skilled coremakers in the foundry. Each core carrier is an accurate replica of the actual corebox and enables the female coremaker to produce the most intricately shaped cores without the danger of scrap due to distortion during the drying operations. Fig. 12 shows a group of cores in position in cast-iron core carriers, from which it will be clearly appreciated that core distortion in drying by the use of these shaped carriers is entirely eliminated. Each core carrier is jig drilled and fitted to fine limits of accuracy to match up with the master corebox, and provided the iron castings are suitably designed and heat-treated, will continue in production for an indefinitely long period.

FOUNDRY CONTROL LABORATORY

The closest possible control of foundry materials and technique is exercised by the laboratory. Although officially none of the castings on the Merlin XX engine is classified by the A.I.D. as a Class I inspection piece, yet every casting is treated in its early production stages, or after design or other modifications have taken place, as a Class I casting. With newly designed components, the first castings produced from a pattern are passed to the foundry control laboratory for X-ray and photomicrographical examination, mechanical testing, etc., and only after a laboratory sanction has been received is a new part released for production. Once this release has been given, no changes in technique are permitted without laboratory agreement and further thorough investigation.

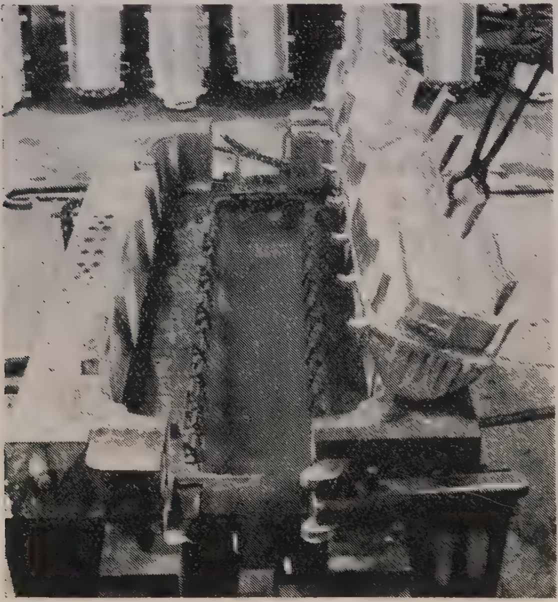

FIG. 10.—MERLIN XX ROCKER COVER DIE.

X-ray Examination

The laboratory is equipped with two X-ray units, each housed on either side of a dark room for the developing of films, and linked by means of lead hatchways to facilitate rapid transfer of films for processing. The larger of the two units—a 200-k.v. set—is used for all classes of materials, including aluminium alloys, aluminum bronze, phosphor bronze, silicon bronze, and certain thicknesses of steel and cast iron. Facilities also exist with the larger unit for quick examination of castings by screening, where such a check is considered practical. As an aid to the production of consistently sound engine castings, radiological examination is regarded as a sound economic proposition.

Spectrographic Analysis

The advantage of collaborative work between firms engaged on similar important work who thereby meet the same daily problems can be fully evinced during the review of the foundry control laboratory, particularly the spectrographic laboratory. In the district in which this factory is situated, a systematic pooling of ideas has been instituted by firms equipped with this apparatus. In addition, the manufacturers of the famous RR range of alloys also rendered valuable assistance in the early stages of building up the necessary staff and standards for operating the apparatus.

Spectrographic analysis is very firmly established in this particular laboratory, the unit installed being a Hilger medium quartz spectrograph (Fd. 60 cm.). The normal day's production output in the foundry yields

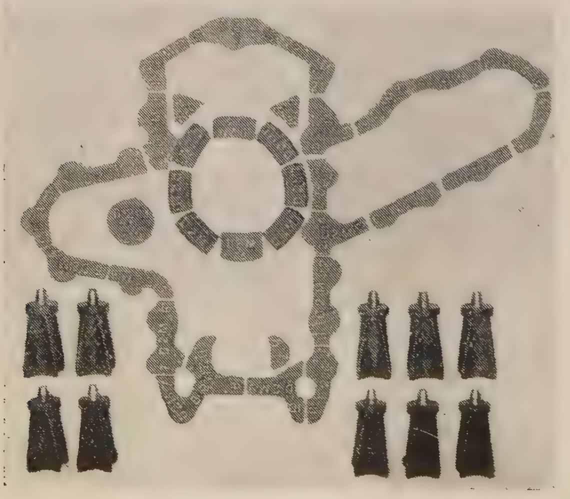

FIG. 11.—TYPICAL SET OF CHILLS FOR MERLIN XX WHEELCASE.

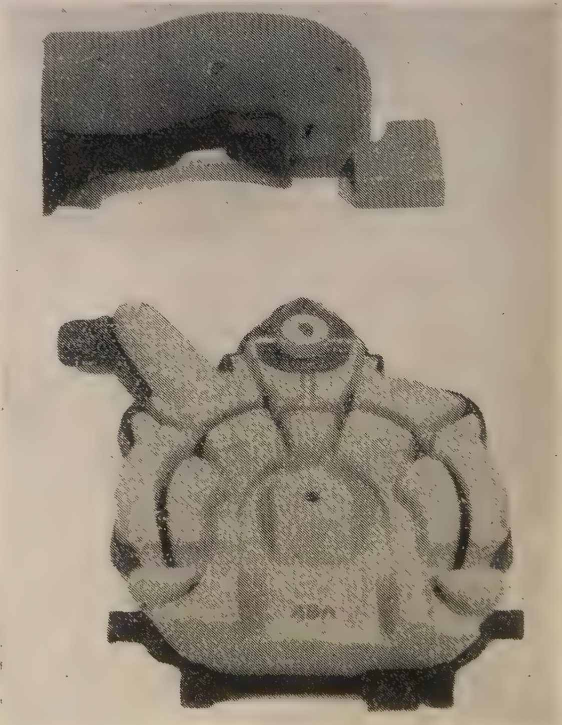

FIG. 12.—TYPICAL GROUP OF MERLIN XX CORES IN CAST-IRON CARRIERS.

over 200 RR50 samples, which are analysed for magnesium on the apparatus, in addition to a full analysis of a percentage of the samples. Obviously the saving in time and labour on the determination of the magnesium content alone in 200 samples per shift by one girl more than justifies the equipment economically. Further developments are under way, on the use of the spectrograph in connection with foundry problems and the conservation of light alloys, which will more than justify the adoption of this method of analysis.

The introduction of female laboratory assistants has been developed to the full, particularly in the chemical laboratory and mechanical testing. In the latter section 2,500 test-bars are pulled for tensile and elongation each normal week.

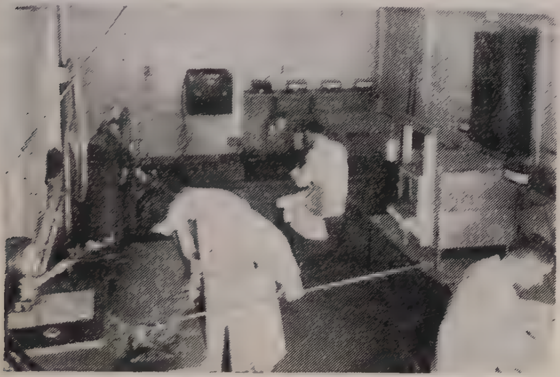

FIG. 13.—CALIBRATION LABORATORY.

Sand Testing

Sand properties are no longer a question of personal opinion, and rule of thumb methods which formed the basis of many a heated argument amongst moulders. The modern apparatus for testing the properties of moulding and coremaking sands enables the laboratory to guarantee from day to day that the sand is consistent in all its important properties. Factors such as grain size, moisture content, green strength, permeability, are now no longer open to argument—they are in this modern foundry laid down rigidly, and maintained to extremely fine limits of consistency.

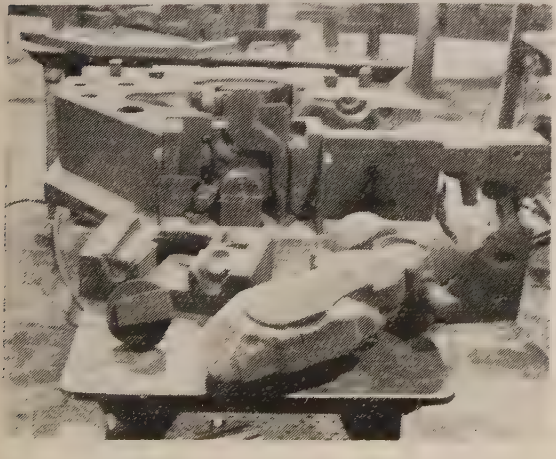

FIG. 15.—CORE ASSEMBLY INSPECTION OF MERLIN XX WHEELCASE CORES.

An August-Simpson miniature sand mixer which is an exact replica of the 5-ton per hr. mixers in the mechanised foundry plant serves to give the laboratory samples of mixed sand on which to carry out tests, the test-pieces being produced under exactly standard ramming conditions, and baked in laboratory size drying ovens, which are thermostatically controlled to any desired temperature. Provision is made for the calibration of all the pyrometers used in the foundry, each instrument being subject to a systemmatic check and overhaul at weekly intervals. In the same department shown in Fig. 13 all the chromel-alumel thermocouples used in connection with the checking of metal temperatures are manufactured. These couples and the pyrometers are carefully checked before issue to the foundry against indicators and platinum-rhodium couples standardised by the National Physical Laboratory. Microscopic examination of samples is fully provided for. The facilities comprise a Vickers (Mark I) projection microscope, bench type Watson and Greenough binocular microscope, along with the necessary apparatus for mounting specimens.

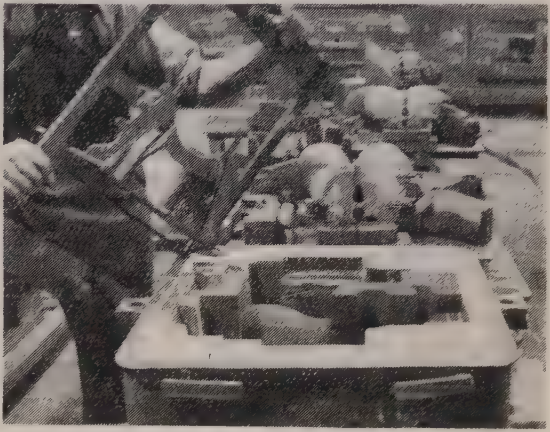

FIG. 14.—CORE ASSEMBLY INSPECTION FOR MERLIN XX INTAKE ELBOW.

Foundry Inspection Operations

In the various phases of the production of light alloy castings for the Merlin XX engine, although inspection operations play a major part, this subject

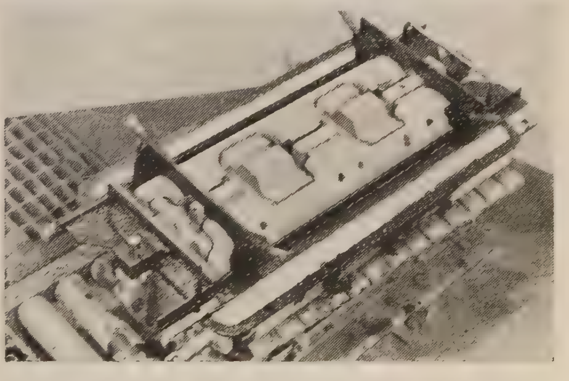

FIG. 16.—GAUGE USED FOR CHECKING POSITIONAL ACCURACY OF BODY CORES ON INDUCTION MANIFOLD.

called for specialised attention, as the Rolls-Royce standard of accuracy for castings has justifiably earned universal commendation. Extreme precision is called for in each casting leaving the foundry, normally the permissible casting wall thickness tolerance being plus or minus twenty-five thousandths of an inch. A very careful weight analysis is maintained of the finished part, and under no circumstances is excess weight permitted. Every possible effort is made in every stage of production to avoid the ultimate loss of time in machining a casting which is not strictly accurate.

New pattern equipment is dealt with similarly to new dies for die-casting. It is first of all passed into a "proofing department," where the first sample castings are produced for X-ray examination by the laboratory, and dimensional inspection by the proof-inspection department. At the same time, all the important factors, such as gating and venting systems, design of production gauges for cores and moulds, pouring temperatures, etc., are determined and recorded for issue to the production foundry. On this first sample casting the proof-inspection department carry out a most rigorous and searching inspection for dimensional errors by the normal surface table method, sectioning the casting in the process to ensure that there are no hidden wall and boss sections which are not of the required strength.

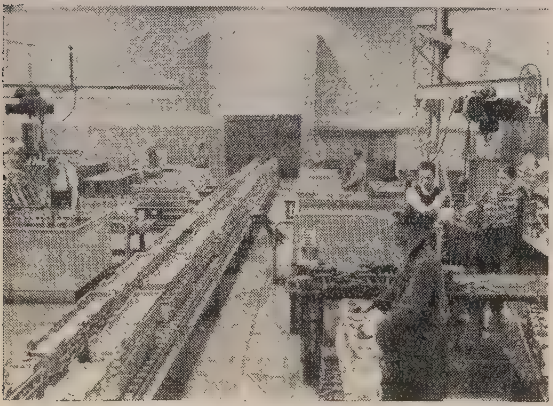

FIG. 17.—INSPECTION AND WATER TEST OF MERLIN XX CYLINDER BLOCK CASTINGS.

The proofed and sectioned casting is then passed to the patternshop, which proceeds to adjust the pattern in line with the findings of the proof inspection, it frequently being necessary to take off up to three proofs before a pattern can be finally released to the production foundry as dimensionally correct. Simultaneously with this dimensional proof inspection, the X-ray laboratory collaborates with the proofing foundry on the establishment of a technique which yields radiologically sound castings, with the result that the patternshop receives the necessary instructions regarding gating, venting and gauging systems in parallel with the dimensional proof reports, and is thus able to release the pattern to the production foundry ready for quantity production without further experiment or delay.

Core and mould gauges and fixtures play an important part in maintaining the dimensional accuracy of castings on large scale production. This is quite easily understood when one realises that upwards of 40 cores are sometimes assembled in a mould, and any one core slightly misplaced is sufficient to scrap the casting. To obviate this, suitable gauges and fixtures are designed for checking the positioning of the cores with a view to eliminating all faults in the early stages of production. An example of a checking gauge and fixture is illustrated in Fig. 14. This consists of a dummy mould for the intake elbow, which is an exact replica of the production mould and is formed by reproducing a mould in stone compound around the actual production pattern, using a standard moulding box for the purpose. Each core is assembled in this permanent mould and checked for metal thickness. The whole assembly is finally checked by a composite gauge located from the pin centres.

Fig. 15 illustrates a partly built-up set of cores for the Wheelcase in a master plate-checking fixture. Owing to the many varied and intricate contours of this casting, the inspection set-up has been designed to check both inside and outside cores. Each individual core is assembled on a master location plate having dowel locations corresponding to those in the ultimate mould. Steel bushes (to be seen in the right-hand core of Fig. 15) are rammed up and dried in the cores for locating on the dowels mentioned. This assembly built up enables the inspector to check each individual metal thickness before releasing cores to the production line.

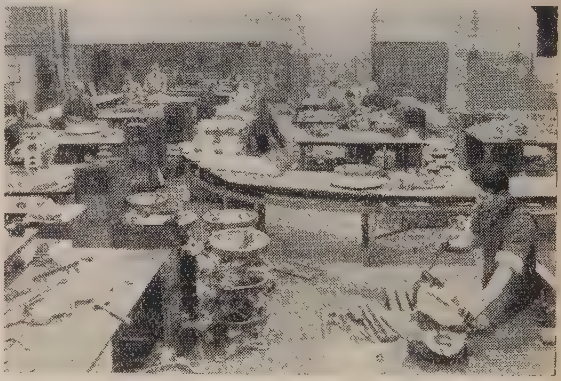

FIG. 18.—CONVEYOR TRANSPORTING CASTINGS THROUGH INSPECTION TO HEAT-TREATMENT.

The positional accuracy of the cores in the mould is checked very carefully prior to casting in all cases by specially designed jigs and gauges, a typical example of which is given in Fig. 16 showing a gauge used for checking the position of the body cores on the induction manifold casting.

Pressure Testing

Pressure testing by means of immersing the casting in hot water and applying air pressure inside the area to be tested is frequently used, and affords a rapid check against porous areas. A typical example is shown in Fig. 17, where a line of cylinder blocks is shown passing through pressure test and final thickness inspection and at the far end of the conveyor discharging into the heat-treatment section. Fig. 18 shows a power-driven pallet conveyor transporting castings through the pressure test and final inspection, and again discharging directly into the heat-treatment section. Female inspectors play their part in the organisation, particularly on the inspection of die-castings. Experience has shown that the reject hazards due to porosity and cracking are highest in die-castings, and for this reason all die-castings are passed through a most searching inspection by chalk testing immediately after the runners and risers have been sawn off, but before any other fettling operations are carried out. The casting to be tested is first of all soaked in a tank of hot penetrating oil, and afterwards covered with French chalk, the oil having first penetrated into any crack or flaw in the casting, then oozes back into the chalk, leaving a very clear indication of the presence of a fault. Female inspectors are also employed on the dimensional inspection of die-castings; naturally, of course, the hazards for dimensional scrap are considerably less on castings produced in permanent moulds than in those produced by sand-casting methods.

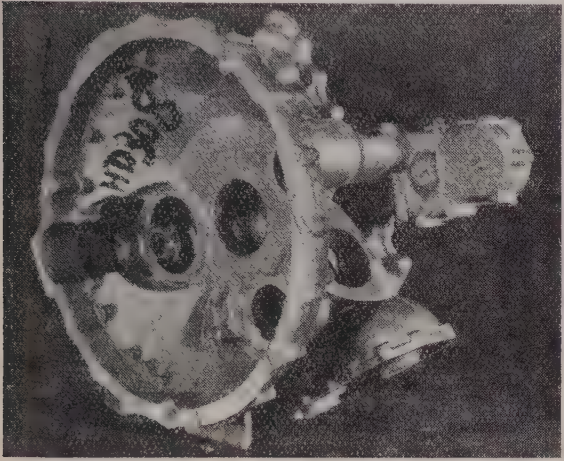
FIG. 19.—MERLIN XX WHEELCASE CASTINGS SHOWING MACHINED LOCATION SPOTS.

Jig and Spot Location Inspection

After the major castings have passed through the heat-treatment furnace and are thus in a stabilised condition, they then receive the final dimensional check for co-relation of general dimensions and location points are machined in them, which are to form the datum from which the machine shops proceed with the machining operations. After reference to Fig. 19, as a typical example, it will be agreed that with complex castings of this description, "marking out" for machining would take a skilled man some considerable time, and since surface table methods of marking out on large castings invariably limit the dimensional check to one plane only, there is a grave risk of failure on the part of the marker-out correctly to co-relate the dimensions of the casting accurately in both planes simultaneously. To overcome this difficulty, special checking fixtures have been designed for checking the important casting dimensions, profiles, etc., in both planes simultaneously, and having "floated" the casting into such a position that all the essential features have been proved correct, a series, usually three, of location faces and dowel holes is machined in the casting from which the machine shops commence their operations.

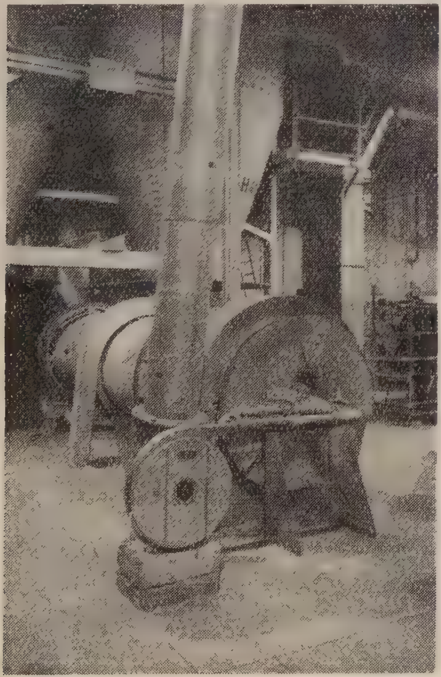
FIG. 21.—CORE SAND DRIER AND STORAGE HOPPERS.

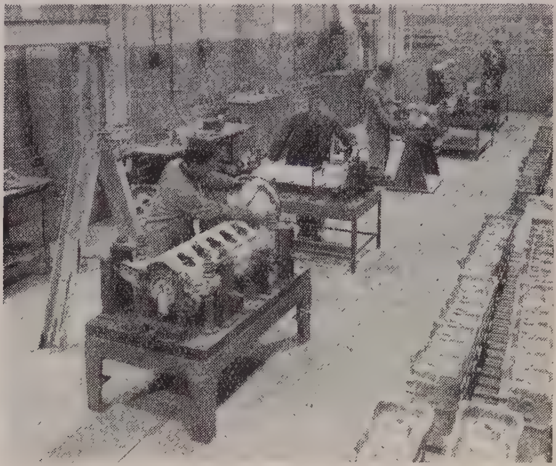
FIG. 20.—JIG AND SPOT LOCATION FIXTURES ON VARIOUS MERLIN XX CASTINGS.

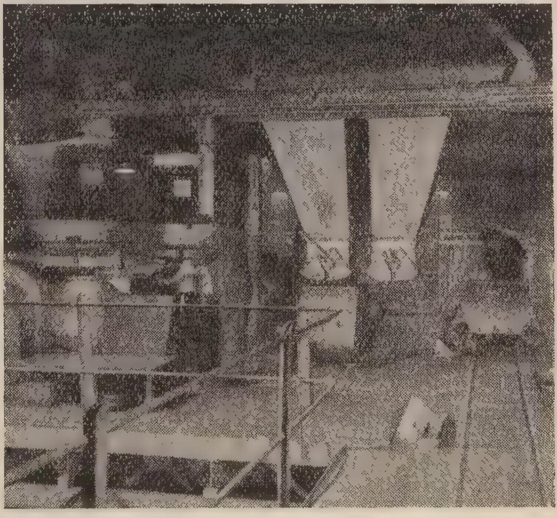
FIG. 22.—CORE SAND MIXER AND DISTRIBUTION BOGEYS ON GALLERYS.

The accuracy of the machining of the location faces is checked by means of a standard clock gauge to limits of plus or minus 0.002 in. By this means, therefore, the foundry has eliminated entirely the possibility of dimensional rejections in the machine shops due to casting errors, and at the same time saved hundreds of hours of highly skilled men's time in the process.

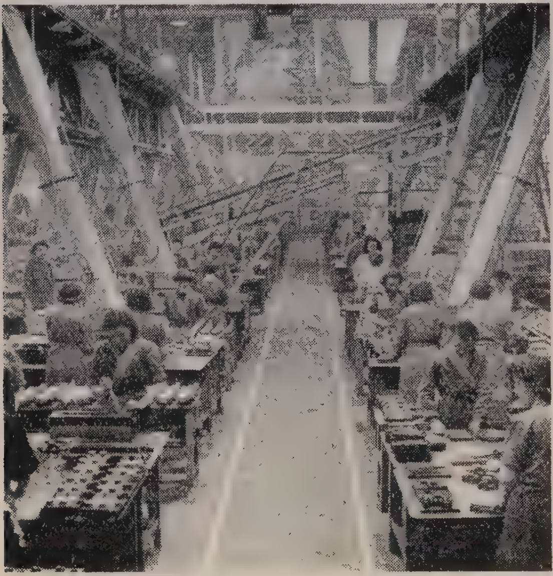

FIG. 23.—VIEW OF CORESHOP.

The average time taken to set up the casting in Fig. 19 in the jig and spot location fixture in the foundry, inspect and machine the necessary location faces and dowel holes is 18 min., which represents a very considerable saving over the very best surface table time possible. Part of the section engaged on this jig and spot location inspection is shown in Fig. 20, where fixtures on the upper and lower half crankcase, wheelcase and cylinder blocks can be seen in operation. The machined and inspected castings are then shown entering the despatch stores on roller conveyors.

THE LIGHT ALLOY FOUNDRY

Whilst mechanisation is fairly commonplace in iron-foundries throughout the country, little or no mass production technique had been introduced into light alloy foundries, and more especially those foundries engaged on the production of really complex aero engine castings. Flexibility of operation and control has obviously been the keynote on which the layout and equipment was planned, provision having been made wherever possible to safeguard continuance of production by a sensible sub-division of the most vital items of equipment.

The layout is planned to give a continuous flow of raw materials from the railway siding at one side of the building into finished castings delivered into the machine shops on the opposite side. In the average foundry not mechanised 275 tons of material are handled to produce 1 ton of castings, whilst in the plant under review this ratio has been reduced to as low as 120:1. Moulding and core sands, delivered by rail truck, are discharged through a grid at floor level outside the foundry, and transported by rotary table feeder and elevator into storage hoppers. Two of these hoppers, each holding 30 tons of core sand, are shown in Fig. 21. This sand, being invariably delivered in a wet condition, is then passed through a large rotary drier with an output of 4 to 5 tons per hr. and discharged into an airlift system which deposits the then dried and cooled sand into a cyclone and then into large storage hoppers immediately over the core-sand mixers in the roof above the actual coreshop.

Core Sand Preparation

Predetermined quantities of this sand are then discharged by batch measures into the core-sand mixers, and the requisite amounts of binding constituents of linseed oil, dextrine and molasses are added, and mixed thoroughly into the sand, according to instructions laid down by the foundry control laboratory, before discharging from the mixers into the bottom opening tubs shown in Fig. 22.

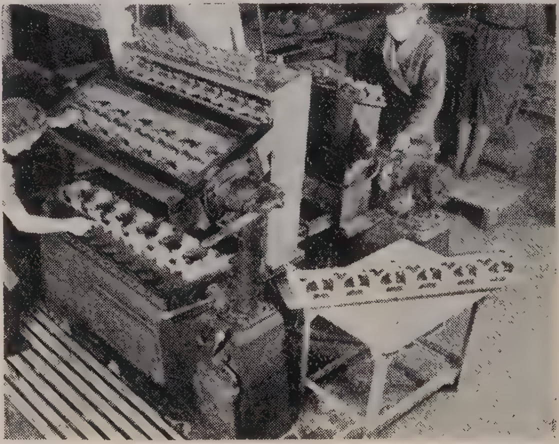

FIG. 24.—MAKING MERLIN XX CYLINDER BLOCK JACKET CORES ON COREMAKING MACHINES.

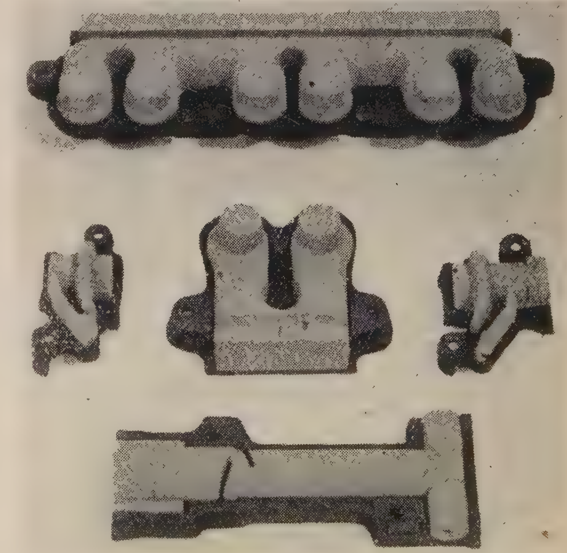

FIG. 25.—GROUP OF SMALLER INTRICATE CORES MADE BY FEMALE COREMAKERS WITH THE ASSISTANCE OF CAST-IRON CORE CARRIERS.

Operated entirely by girls, these bottom opening tubs discharge the mixed core sand directly on to the coremakers' benches, clearly indicated in Fig. 23, the female operators indicating by warning light connected from the hoppers to the distribution platform above, when further supplies of core sand are required. Some idea of the extent to which female labour is employed in this foundry can be gathered from this view of the centre bay of the coreshop in Fig. 23. These girls can be justifiably proud of their reputation for producing really first-class cores at remarkably high rates of production.

Coremaking

Pages could be written of the various manufacturing problems met with by the management in this department, and the ingenious devices developed to overcome these difficulties to render the production of intricate cores by female labour possible. To quote but a few examples of the achievements, a reference to Fig. 24 shows a girl coremaker engaged on the manufacture of the intricate jacket core for the Merlin XX cylinder block, recognised to be one of the most difficult cores on the engine to produce. She is assisted by a coremaking machine, which eliminates entirely all the fatigue of rolling over and stripping a heavy corebox from the finished core to which is fitted a really first-class all-metal corebox. This girl, who is one of several girls trained on this particular core, normally produces 30 first-class cores per shift, with a skill which has astounded even the most highly skilled coremaking craftsman in the industry locally. A further example of how mechanised assistance brings the larger cores well within the scope of a female coremaker, is shown in the manufacture again on a rollover core machine, of a large block core for the Merlin XX wheelcase casting.

A further group of intricate cores manufactured by girl coremakers with the assistance of cast-iron core carriers, which are an exact replica of the corebox already mentioned in the description of the patternshop, is given in Fig. 25. Without this specialised method of assistance, the work in connection with these cores would be well outside the capability of the girl coremakers, which all goes to prove that, provided the necessary facilities are given, the possibilities of girl labour in core production are unlimited.

Steel band conveyors are used for transporting the cores from the coremakers' benches to the core stoves, the lower strand of the conveyor being used for the return of the coreplates to the coremakers' benches.

All the auxiliary operations such as preparing and bending to shape the wires used to reinforce the core, sorting and preparing chills for insertion in cores, are dealt with in sections occupied whole time on this work. The result is that the female coremakers keep the valuable pattern equipment in full-time operation and readily become expert, whilst for example in the core wire-bending section, other girls have developed a knack of turning out thousands of wires bent accurately to shape in jigs prepared for the purpose.

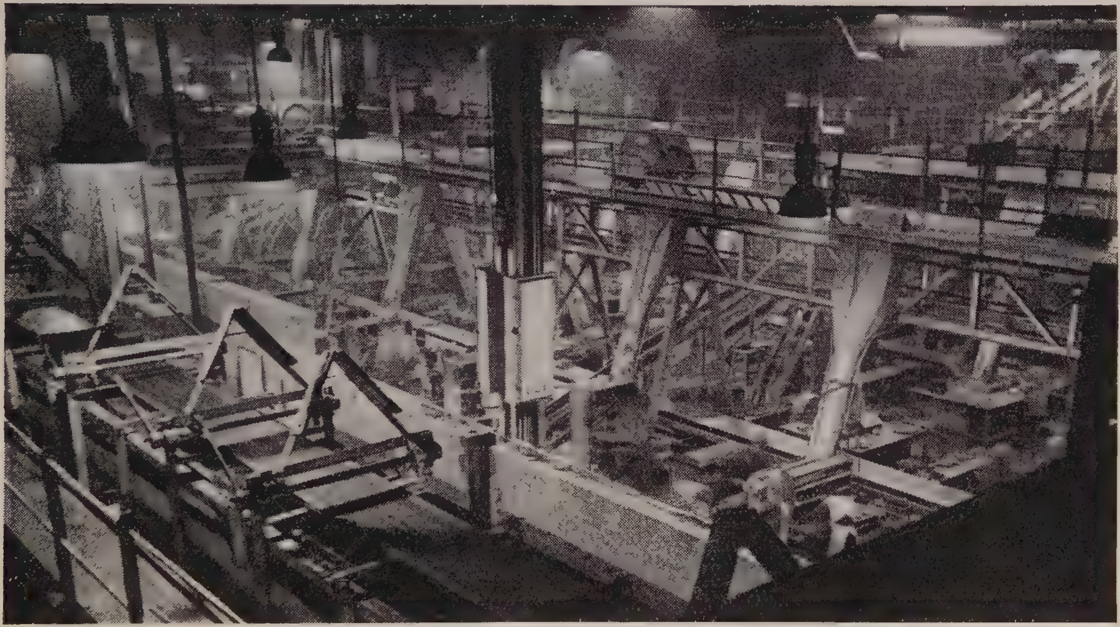

FIG. 26.—VIEW OF CORESHIP FROM GALLERY.

An interesting side view of the coremaking department is shown in Fig. 26. One of the two 170-ft. long steel-band conveyors can be clearly seen between the lines of coremakers' benches, whilst the combination of coresand mixing, distribution, and hopper supply is illustrated particularly well. The baking of the cores is carried out in continuous, automatically-loaded, vertical core stoves of varying sizes to suit different types of cores, the baked cores being discharged on to one of two pendulum-type conveyors, which carries them through the remaining operations into the moulding bay ready for setting in the moulds.

Coredressing

Each individual core as it arrives at its appropriate station on the pendulum conveyor is carefully trimmed to remove all flashes of sand, checked with inspection gauges and painted where necessary, before passing to group inspection, where its accuracy in relation to the remaining cores which go to complete a set is checked.

Certain of the cores in an assembly may be gas-tested to ensure that the venting system is satisfactory. This gas-testing operation is illustrated in Fig. 27, where a volute core for coolant pump is shown with a bad leak through which the gas circulated inside the venting system is leaking and has ignited. Obviously, this leak, unless detected and sealed, is a potential source of danger due to either metal entering the core and choking the vent, thus preventing the egress of gas from the core, or to trapped core gas being expelled on expanding after the pouring operation into the aluminium in the molten condition, and creating an aluminium oxide inclusion in the casting.

Group inspection on the wheelcase casting has already been described in connection with Fig. 15. Obviously, by this method, the human element is eliminated in the operation of core setting, and it is, therefore, possible to group-inspect a set of wheelcase cores and guarantee that all sectional thicknesses will be correct on the later setting in the mould and in the ultimate casting.

After passing group inspection, the completed set of cores is reloaded on to the same pendulum conveyor and transported by this means through a drying tunnel to ensure that the last vestige of moisture is dried out of the cores before they pass into the core stores ready for issue to the moulding bay.

The general view of a portion of one of the core-dressing sections in Fig. 28 shows the pendulum conveyor passing through the drying tunnel at the far end and returning into the core stores immediately behind the moulding bay. Here again in the core-dressing section female labour has been introduced to a very large extent. Some idea of the magnitude of the core production problem can be gathered from the fact that there are over 300 individual cores used on the production of every Merlin XX engine.

Moulding-Sand Preparation

The generally accepted practice, and one which still prevails in many light alloy foundries, that the moulding sand used for the production of satisfactory aluminium castings must comprise two distinct qualities, namely, facing sand and backing sand, has been well and truly exploded. Here, the whole of the moulding sand in circulation in the mechanical handling system at a rate of 15 tons per hr., is of uniform composition, and is used for both facing and backing.

Furthermore, it is not synthetically-bonded, but is produced by careful blending of naturally-bonded sands under laboratory control to give the required properties for mass-production methods. This important factor of maintaining a uniform sand throughout the whole of the moulding system obviously eliminated a serious bottle-neck in the drive for quantity production.

The plant installed for mixing, distribution and reconditioning the moulding sand is outstanding, and deals with the problem in a manner which enables and assists the laboratory to maintain this rigidly scientific control at all stages in the processing. The various naturally-bonded sands are delivered, as mentioned earlier, by rail truck and discharged through a grid at floor level into the moulding-sand storage hoppers inside the foundry building. Batch mixing is carried out in a battery of four August-Simpson mixers, each of which has an output of 5 tons per hour.

Batch mixing of moulding sand is regarded in this foundry as an all-important and essential condition as opposed to continuous mixing in the maintenance of scientific sand control. With batch mixing, accurately controlled percentages of new sand and moisture can be added to each batch of known volume, whilst carefully predetermined mixing and mulling periods can be maintained to ensure absolute uniformity of sand conditions throughout the foundry.

Fig. 29 is a general side view of the mixing section for moulding sand, showing an inclined conveyor in the foreground which is the first stage in the distribution to the foundry, whilst in the background of Figs. 30 and 31 can be seen the storage hoppers above each moulding machine, into which the mixed sand is finally discharged ready for use.

Moulding

There are two main moulding bays in the foundry, each of which is arranged to produce complete balanced sets of Merlin XX engine castings, these bays being arranged on either side of a battery of 16 tilting furnaces which supply the molten metal to both bays.

The moulding bays are sub-divided into sections, each of which is planned and arranged to produce a specific casting on the engine at the required balanced rate of output. All moulds are produced on moulding machines by semi-skilled male and female labour, each of whom remains so far as practicable a specialist on a particular casting. Various types and sizes of rollover-jolt moulding machines according to the size, jolt load and pattern draw required are used, but in all cases, despite complications such as inserted chills, etc., the full advantage of a rollover-jolt machine has been used.

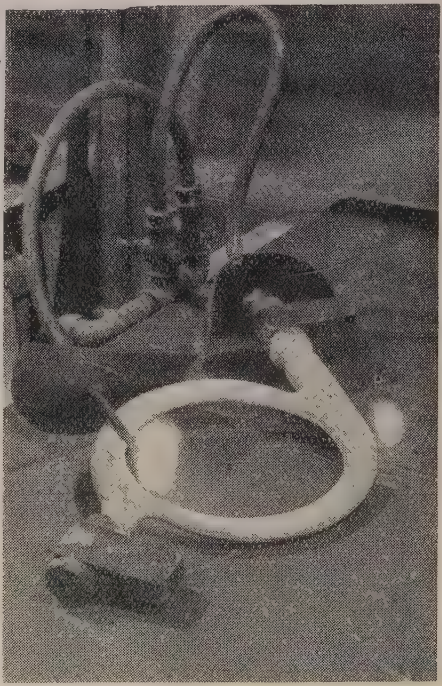

FIG. 27.—GAS-TESTING A VOLUTE CORE FOR A DIE-CAST COOLANT PUMP (NOTE LEAK INDICATED BY ARROW).

The moulds for the upper half crankcase shown in Fig. 32, which is the largest casting on the Merlin XX engine (weight fettled, 212 lbs.), are produced on a 44 by 72-in. rollover jolter—one stage in the production of the mid part mould being illustrated in Fig. 33. In this particular mould, there are upwards of 40 loose chills and core locations, which are successfully jolt rammed in position by carefully synchronising the rate and intensity of the

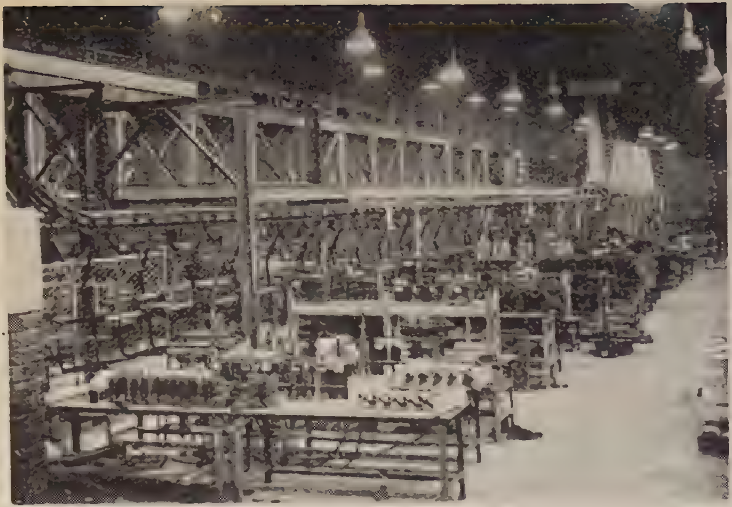

FIG. 28.—GENERAL VIEW OF COREDRESSING SECTION.

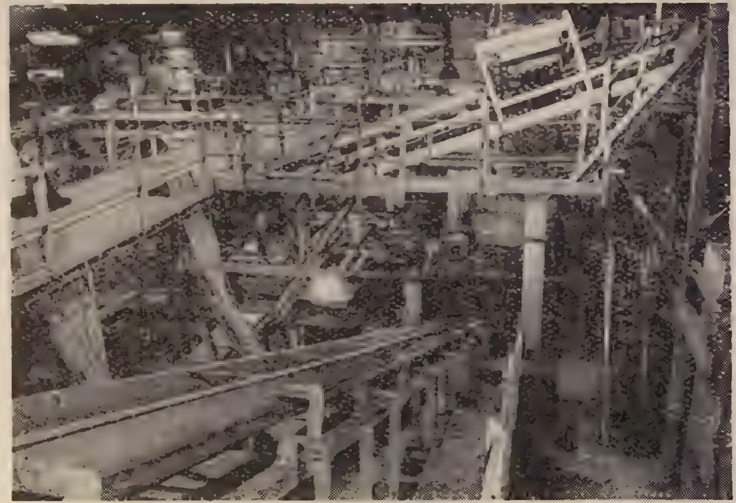

FIG. 29.—GENERAL VIEW OF SAND-MIXING SECTION SHOWING INCLINED CONVEYOR AND MAGNETIC SEPARATOR.

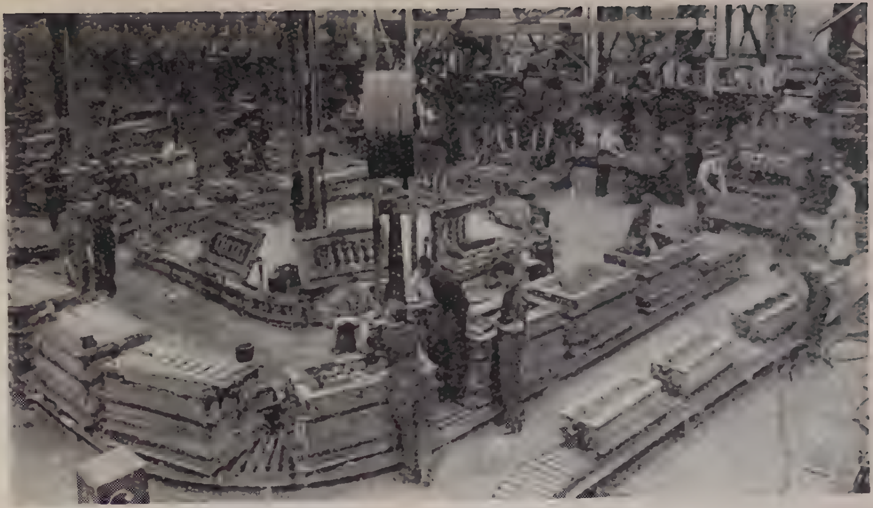

FIG. 30.—MERLIN XX UPPER HALF CRANKCASE MOULDING BAY.

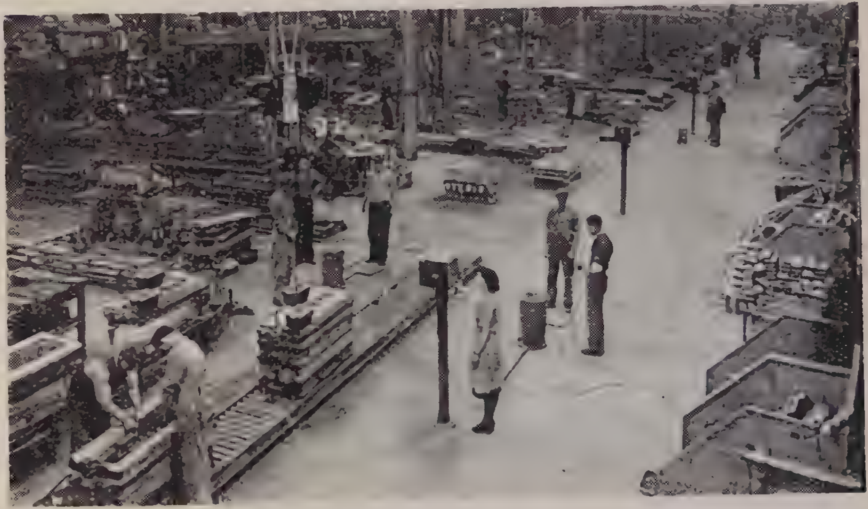

FIG. 31.—GENERAL VIEW OF ONE OF THE MAIN MOULDING BAYS IN THE FOUNDRY.

jolt mechanism on the machine with the combined pattern, sand and moulding box weight of 1 ton.

Control of the flow of sand from the overhead hoppers into the moulding box on the machine is by means of an electric foot control, shown in the foreground of Fig. 2. By this means, the machine moulder retains both hands free for the placing of chills and spreading the incoming sand during the jolting operation. No cutting of runners or risers by hand methods is necessary on the completed moulds, all of these having been incorporated on the pattern plate, so that once produced, these moulds are transferred directly on to gravity roller conveyors where they are sprayed and dried, ready for the insertion of the various internal cores.

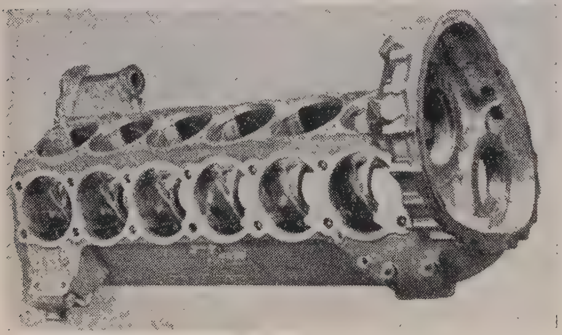

FIG. 32.—FINISHED UPPER HALF CRANKCASE.

The drying of the moulds normally carried out by gas torches is done automatically by the stationary unit shown in Fig. 34. By this means, each mould receives a specific drying period at a controlled temperature sufficient to ensure no deleterious effects in the ultimate casting due to " blows " from an insufficiently dried mould. The later stages in the production of the upper half crankcase are shown in Fig. 30 where the operators " coring up " are clearly illustrated prior to the transfer of the " top part " mould from the trunnion track in the background, and the final " casting " operation shown in Fig. 35.

Similarly throughout the whole length of each of these bays the different engine casting moulds are produced, finished and the internal cores set in position to fine limits of accuracy.

After the actual pouring of the casting the moulding sand passes through grids in the floor and is returned to the sand plant for reconditioning by underground conveyors. These floor knockout grids are equipped with an air suction system extracting, in all, over 70,000 cub. ft. of air from the foundry, thus rendering the operation of casting knockout entirely dust free, and removing entirely the danger of any of the floating dust, created during the knockout operation, entering any of the adjacent incompleted moulds.

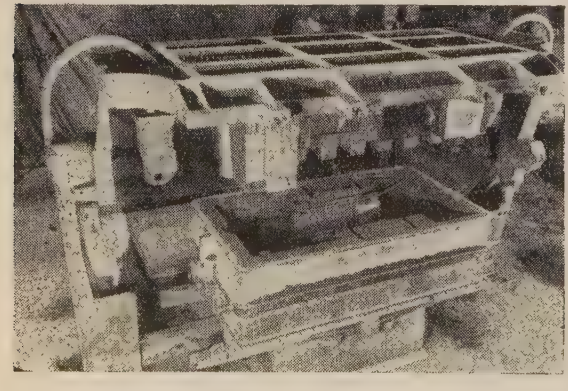

FIG. 33.—MERLIN XX UPPER HALF CRANKCASE MOULDING MACHINE (POS. 1).

Melting Practice

The type of melting furnace used is clearly illustrated in Fig. 35, showing one of the battery of 16 5-cwt. capacity crucible furnaces with lip-axis tilting, and arranged with a back flue for exhausting the furnace gases well clear of the crucible. These furnaces are supplied with alternative fuels as a safeguard against production stoppage due to a failure in the supply of either heating medium. The principal alloy used in the manufacture of the castings for the Merlin engine is the well-known RR50. Each individual casting on the Merlin engine has been carefully studied by the laboratory to arrive at the optimum pouring temperature, which is carefully checked by female operatives with temperature recorders.

Core Removal and Fettling

After the actual pouring operation the castings are, as stated previously, transported to the finishing section, the first operation of which is the removal of cores. This used core sand is removed from the

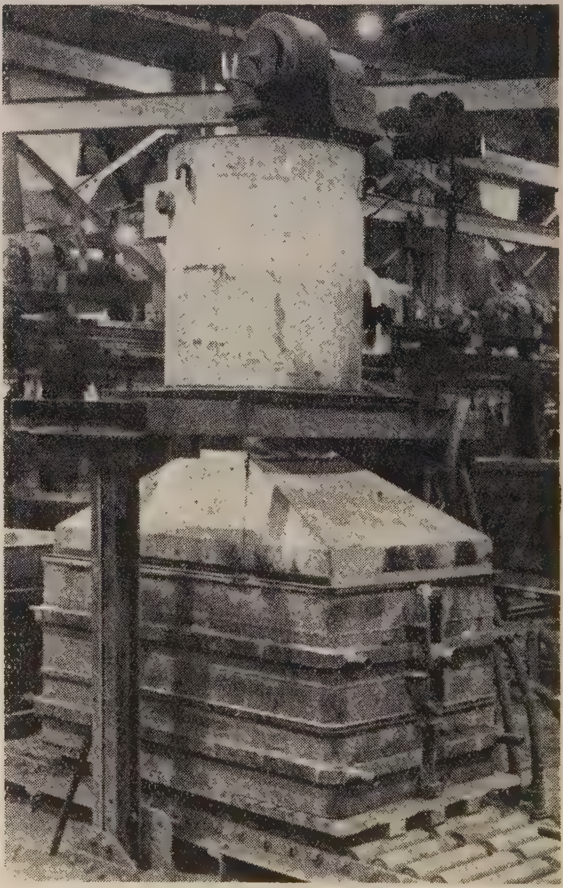

FIG. 34.—AN AUTOMATIC MOULD DRYING UNIT ON UPPER HALF CRANKCASE MOULDS.

casting and falls through special grids on to a conveyor which transports it out of the foundry into storage hoppers ready for carting away for disposal. During the discharge of this refuse core sand, any chills or tramp iron is removed by means of a magnetic separator, and small pieces of flash aluminium are removed by hand. From the core knockout, the castings then pass to one of a battery of bandsaws or circular saws which remove the runners and risers. There are, in all, 15 of these bandsaw machines of varying capacity in operation. From this point, according to the size of castings, the larger castings pass on gravity roller conveyors and the small castings by means of a power driven conveyor, to the fettlers.

Fig. 36 shows these bandsaws with a power driven plate conveyor transporting castings from the saws to the later operation of grinding, fettling, and later on to various inspections and heat-treatment, whilst Fig. 37 shows a special new type twin metal-cutting circular saw, removing feeders and risers from both top and bottom of a cylinder block simultaneously. This machine was specially designed and produced for the purpose, and carried out the operation in an actual cutting time of 3½ min., the table of the machine being power driven, with a quick return motion after the cutting operation is completed.

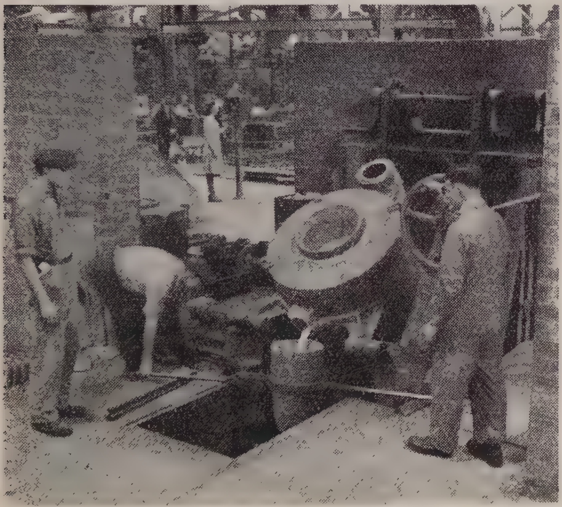

FIG. 35.—POURING METAL FROM MORGAN 5-CWT. TILTING FURNACE.

The whole of the fettling of the larger castings is dealt with by male operatives, but the bulk of the medium and smaller work is handled by trained female fettlers, all of whom are proficient in the use of pneumatic chippers. Experienced male fettlers are used on a complicated casting calling for a high degree of skill. After the fettling operations have been carried out, the castings are reloaded on the respective conveyors and passed forward to the next operations of inspection and heat-treatment.

Heat-Treatment

After the casting has passed inspection it is transported by conveyor to the heat-treatment furnace (Fig. 38), from which it will be seen that loaded bogies are intermittently charged into the furnace by push-button controlled electrical pusher gear. The furnace is 88 ft. long and is divided into three zones, preheating to bring the charge up to the correct temperature; soaking, in which chamber the castings remain for an 8-hr. period; and, finally, cooling. The intermediate doors between the various zones are electrically interlocked with the pusher gear, and transfer cars so that the operation of the furnace is as nearly foolproof as possible.

Rapid recirculation of hot air is the heating medium used, no products of combustion being allowed to enter the furnace. The air is heated by means of two large air heaters which are located above the furnace. The accuracy of the control of temperature which is regulated and maintained by fully automatic pyrometric control gear, being of the order of plus or minus 2 deg. C. of the desired figure throughout the full length of the preheating and soaking zones.

Wired to each casting before entering the furnace is the appropriate test-bar to conform to A.I.D. requirements, so that all castings leaving the furnace are discharged into quarantine stores pending the completion of the mechanical tests on the bar and the issue of the release note.

Obviously, there are several outstanding advantages of this type of furnace over the batch type. First, the whole of the castings processed (approximately 30 cwts. per hr.) are loaded, treated and discharged by one man; secondly, economy in fuel costs; and thirdly, absolute uniformity of treatment with the continuity of line flow production.

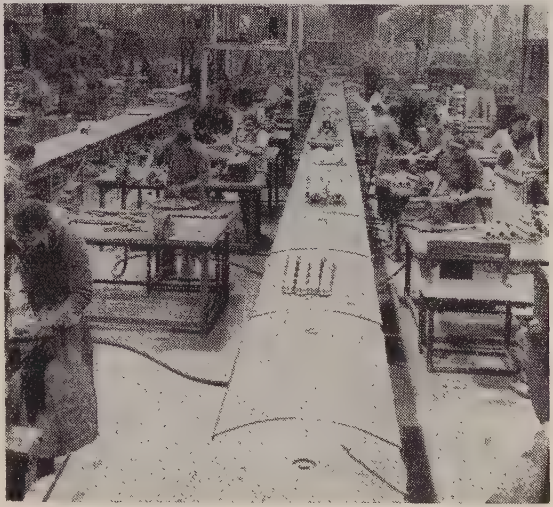

FIG. 36.—GENERAL VIEW OF FETTLING SHOP.

ALUMINIUM DIE-CASTING

The advantages to be gained by casting aluminium alloys into metal moulds, whether by gravity or pressure methods, can be generally covered by three principal factors:—(1) Increased rates of production over sand-cast methods; (2) narrower limits of dimensional accuracy are possible; and (3) improved mechanical properties of the casting. Of the 147 castings in the Merlin engine, 101, or 76 per cent. of the total, are produced as die-castings.

Some of the castings produced involve the use of sand cores, although the foundry die designers, in collaboration with the production engineer, endeavour to modify designs to eliminate the use of sand, or multi-piece cores as far as possible. There are numerous examples of how designs have been altered by the production engineer at the request of the foundry, with the result that potential causes of scrap castings were eliminated, and production output from the die greatly increased.

The whole of the design and manufacture of a new gravity or pressure die is carried out within the foundry organisation, and on completion the new die is passed into a "proofing" die-casting department, where the best method of coating the die and pouring the casting along with other essential features, such as pouring temperature, production rate, etc., are determined. With these essential details tabulated, the die is then released to the production die-casting department.

There are three alloys in general use in the die-casting section, namely, B.S.S. 4L11, B.S.S. L33, and B.S.S. RR50. The use of 4L11 is generally limited to those die-castings in which the best possible bearing properties are required, whilst L33 is used mainly in the production of castings such as the rocker cover (see Figs. 8, 9, and 10), which could not be produced in RR50 satisfactorily owing to its long thin design necessitating maximum fluidity in the alloy used.

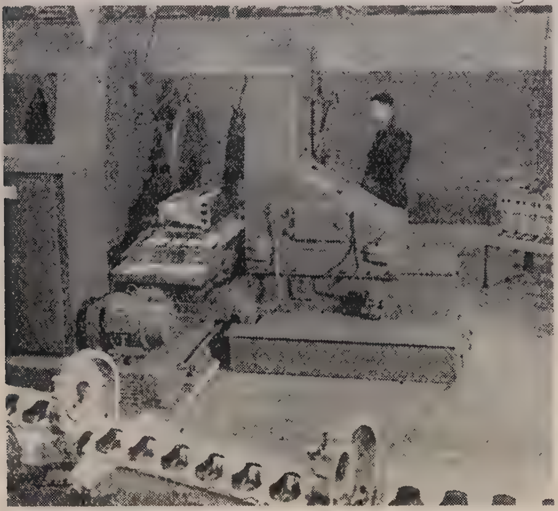

FIG. 37.—TWIN CIRCULAR SAW CUTTING MERLIN XX CYLINDER BLOCK CASTINGS.

In cases where the casting is heavily undercut or where it would be impossible to use a steel core, sand cores may be used and removed from the casting by knocking out afterwards. Such an instance is the die for the coolant pump casing shown in Fig. 39 and cast in RR50 alloy. Due to the presence of sand cores which have to be renewed after every casting this is not a die-casting in the true sense of the word, and is sometimes referred to as a semi-die-casting.

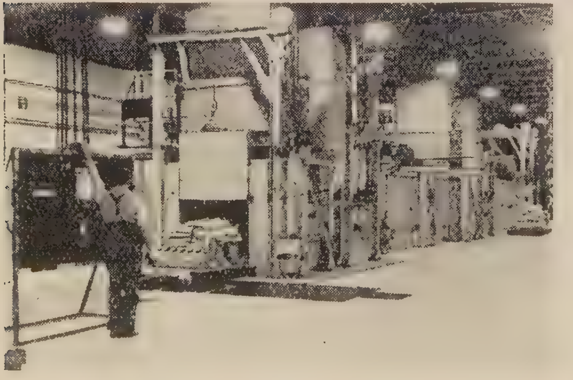

FIG. 38.—CHARGING CASTINGS INTO HEAT-TREATMENT FURNACE WITH ELECTRIC PUSHER GEAR.

The design of dies with sand cores involves problems similar to those met with in sand-casting practice, namely: (*a*) The provision of a suitable design of core print which will ensure accuracy and consistency in core location; (*b*) adequate venting arrangements for drawing off the core gases generated at the moment of casting. Both these conditions are provided for in the design of the coolant pump die shown.

The volute core is located and set at the ends as shown, whilst venting is effected by running a vent right through the core and exhausting at each end to atmosphere. The smaller centre core in the illustration (Fig. 39) is located on its base on four pins projecting out from the bottom of the die. Owing to the fact that this core forms a blind pocket in the casting and that core gases naturally tend to rise, venting by ordinary methods is difficult. For this reason, the four location pins mentioned above are tubular in form, and a system of artificial venting which draws out the gases through the base of the die is used.

After pouring the casting the die is parted and the casting is removed from the die base by means of ejection pins pushing on appropriate places of the casting and connected to an ejector mechanism operated by a rack and pinion arrangement incorporated in the

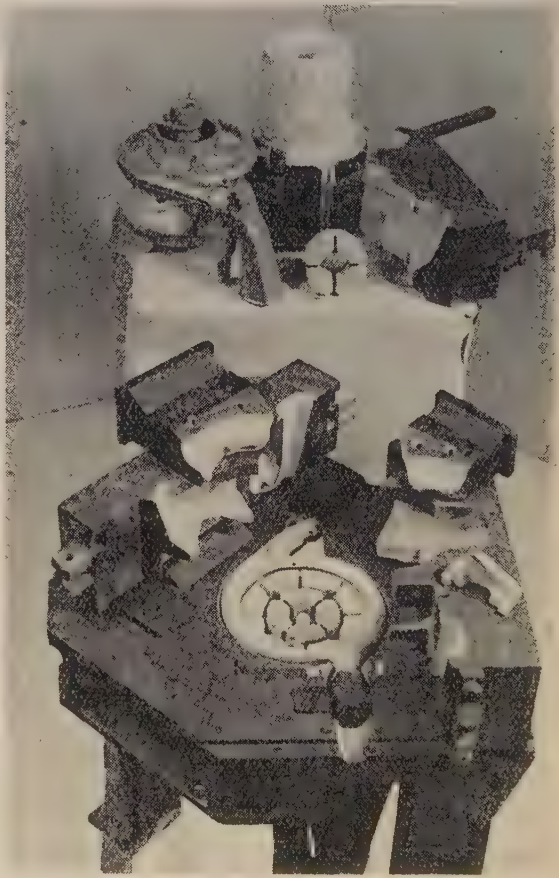

FIG. 39.—COOLANT PUMP GRAVITY DIE.

base of the die. By this means, the casting is removed easily from the die without distortion or, in the extreme cases, cracking. The die for the cover plate and guide and a casting therefrom complete with runners and risers is shown in Fig. 40. The alloy used is again RR50. Owing to the complicated shape of the casting, this part is difficult to produce as a die-casting without a combination of good die designing, accurate tool making and sound die-casting foundry practice.

From the die designer's point of view, it is obvious that the irregular form of the casting demands a smooth flow of metal to the bottom of the die cavity, then filling by displacement to produce castings free from the defects inherent to turbulent pouring. At the same time, consideration must be given as to the most favourable thermal conditions existing in the mould, that is, progressive solidification towards the source of feed or heat. To obtain the ideal conditions, the down runner has been broken across half way up the casting into a boss which requires feeding and then into the bottom of the ring riser where hot metal is most essential. The down runner is inclined at an angle to promote a smooth flow of metal into the die.

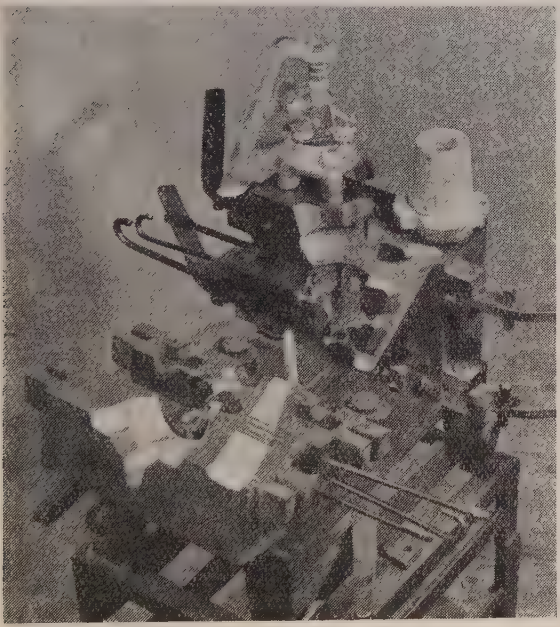

FIG. 40.—COVER PLATE AND GUIDE GRAVITY DIE.

The large number of undercuts present on the casting makes it necessary for most of the shape to be incorporated in loose pieces which are picked off the casting after opening the die blocks. Owing to the fact that all these loose pieces are located and slide in the main die blocks, it is essential that the blocks open perfectly parallel to avoid wrenching the loose pieces which would lead to cracks on the casting. To overcome this difficulty, the blocks run in guides and a special opening device has been included on the die base whereby pressure on the handles projecting out from the side of the base rotates the cams shown, and opens the blocks an equal amount on each side of the joint line, thus leaving the casting suspended on the bottom core. One small sand core clearly shown in Fig. 40 is used to form the triangular shaped pocket on the casting.

Although the design is made as foolproof as possible, considerable skill and care are required in the manipulation of this die, in order to avoid damage to the delicate cores and ensure its correct position and alignment. Besides having an insulating and protective coating on them, the loose pieces are dipped after every cast in a suspension of graphite and water, the purpose of which is lubrication to facilitate easy withdrawal from the casting. After dipping the pieces are suspended over a gas ring to maintain them at a uniform working temperature. Despite the fact that there are 5 pick-off pieces, 8 cores and a sand core, two men can maintain a production of 12 castings per hr. with less than 5 per cent. rejections.

A further example of a semi-die-casting die is shown in Fig. 41. The casting is the fuel pump and is made in B.S.S. 4L11. A sand core is shown in Fig. 39, together with an underneath view of same, indicating the core-printing system. Owing to the relatively even section of the casting and the characteristics of the alloy being cast, a single header is sufficient to provide feed and at the same time act as a runner. Care is required in pouring, however, by this method to avoid sand being washed off the core, as well as air locks and oxide inclusions.

A typical casting representative of many produced by the die-casting process is the boost control casing, made in RR50 alloy. This particular instance reflects the great advantages to be gained by die-casting. In comparison to the die-casting, the sand-casting is difficult to produce, owing to the fact that numerous cores have to be used in the construction of the mould these increasing cost and slowing up production, besides involving high risk of scrap due to the number of hands the mould passes through before completion. Furthermore, the presence of cores and chills in the mould leads to the appearance of flashes and chill marks, resulting in a casting of much inferior finish and accuracy.

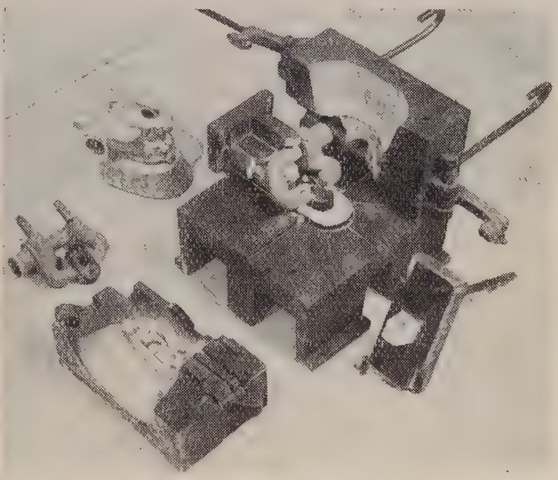

FIG. 41.—FUEL PUMP GRAVITY DIE.

Casting Suitable for Die-Casting

On the other hand, the form of the casting and the disposition of the thick and thin sections lends itself to die-casting, allowing the designer to design quite a simple die of reasonable initial cost capable of producing thousands of sound castings. The casting is situated in the die in a manner which ensures sufficient feed to all heavy sections, whilst maintaining simplicity in design. The casting is top poured by a skilled caster, the metal entering the mould slowly with the minimum of turbulence. Where top pouring is employed, ample ventilation of the die cavity is essential to allow for a free egress of air in front of the ingoing metal. For this reason, numerous risers have been placed all round the casting to give direct ventilation to the atmosphere.

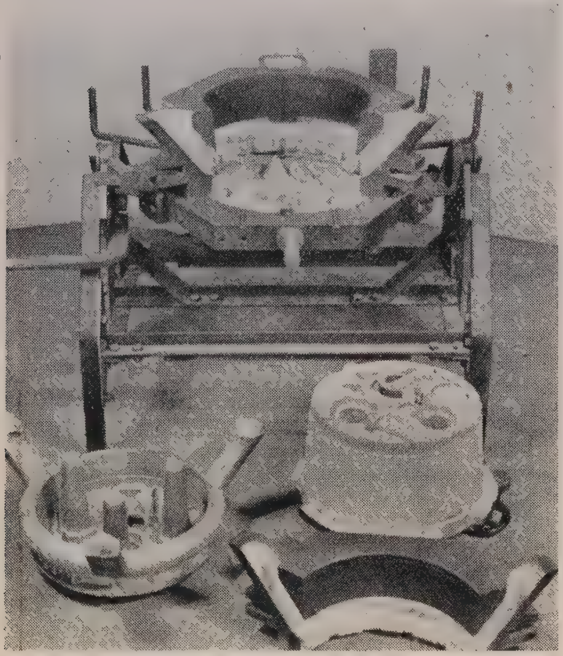

FIG. 42.—GEAR GASING DIE.

The gravity die for the front gear casing and a casting therefrom is shown in Fig. 42. This is cast in RR50 alloy. Close co-operation between the die designer and the production engineer is essential on a job of this description, in an endeavour to make the job as simple and straightforward as possible, with a view to deleting any unnecessary undercuts, and allowing ample taper for extracting the casting from the die when cast. Any design alterations of this description are, of course, permissible only provided the function and strength of the casting is not in any way impaired.

As can be seen from Fig. 42, the die consists of a substantial die base in which is situated a large core. This contains all the bottom form of the casting and is actuated in a vertical direction by means of three equally spaced "two-start" square threaded screws connected by a link motion and operated by a single lever projecting out from the side of the die. The circumferential contour of the casting is contained in three form blocks sliding in guides on the die base. These form blocks also embody the runners and risers. The internal portion of the casting is formed with one large core located in the runner blocks.

Owing to the nature of the alloy used, adequate feeding of the metal during solidification is necessary and for this reason a heavy riser has been placed all round the casting in order to feed the flange and the heavy bosses thereon. The three heavy bearing bosses and adjacent thick sections in the bottom of the casting are fed by means of the conical risers shown. Besides ensuring a casting free from all shrinkage defects, adequate venting of the die is also necessary to maintain good definition and obviate misruns. Webs are vented by splitting the core along their length and venting the joint lines thus formed; where jointing is impracticable, split vent plugs are inserted at appropriate places.

The metal is poured into the die at a temperature of 710 to 720 deg. C. down the three sloping runners; these ensure a smooth flow of entering metal, resulting in castings being free from air inclusions, whilst a three-position pour is advantageous, as it maintains a uniform temperature throughout the mould and individual rates of pour are kept to a minimum, thus alleviating the risk of turbulence.

It is obvious that a great saving in time and money can be effected by making a casting of this description from a die, as compared with the sand-casting process, both from the foundry and machine-shop points of view, as casting can be maintained to a consistent degree of accuracy and uniformity with a much superior finish.

Conclusion

In conclusion, the authors wish to thank Mr. E. W. Hives, General Manager and Director of Rolls-Royce, Limited, for permission to publish this Paper.

Paper No. 782

The Mass Production of a Manganese Steel Casting*

By J. W. GARDOM, A.M.I.Mech.E.

Introduction

Soon after the outbreak of war it was necessary to increase very considerably the facilities available for the production of tank track links in manganese steel. The Technical Committee of the Institute of British Foundrymen was asked to design and equip a number of new foundries capable of mass producing these castings and the author, as Convenor of this Committee, was closely associated with the work. As a consulting engineer, the author was at this time engaged in designing a plant for the production of a casting in mild steel. Some of the equipment had already been installed when it was necessary to change over this plant for the production of the same manganese steel casting. It was thus possible to use this plant as a pilot for the new foundries. This Paper gives an account of some of the problems encountered and the methods finally adopted in the pilot plant.

Manganese Steel

For those who are not familiar with the properties of manganese steel, the following brief description is given. Manganese steel is the name given to alloys of iron, carbon and manganese, in which the manganese content is within the range 11 to 14 per cent., with a carbon content of 1.0 to 1.4 per cent. The ratio between the manganese and carbon contents is important and in the most satisfactory steels the carbon is not more than, and preferably a little less than, one-tenth of the manganese. For the best results it is desirable that the composition of the steel shall be kept within the following limits:—Carbon, 1.0 to 1.3 per cent.; manganese, 11.0 to 13.0 per cent.; silicon, 0.5 to 0.8 per cent.; sulphur, 0.06 per cent. max.; and phosphorus, 0.10 per cent. max.

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* This Paper was the Institute's exchange Paper to the 1943 Annual Convention of the American Foundrymen's Association. For this reason all British weights have been converted to American, which explains why some are not round figures.

In the as-cast state the steel is relatively brittle, inasmuch as thin sections can be readily broken by blows from a hammer. After heat-treatment, the metal is extremely tough and practically unmachinable. In both the as-cast and heat-treated conditions it is for all practical purposes non-magnetic. The contraction which takes place on cooling from the molten state is high, at approximately $\frac{5}{16}$ in. per ft., compared with the $\frac{1}{4}$ in. per ft. allowance usually made for mild steel. The thermal conductivity of the metal is extremely low, the usually accepted value being 0.027 c.g.s. units (0 to 100 deg. C.), which is only one-fourth to one-fifth that of mild steel.

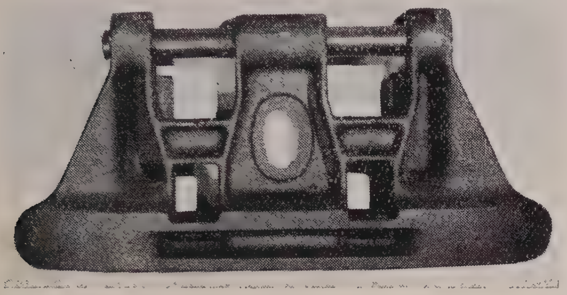

FIG. 1.—MANGANESE STEEL TRACK LINK. FRONT VIEW.

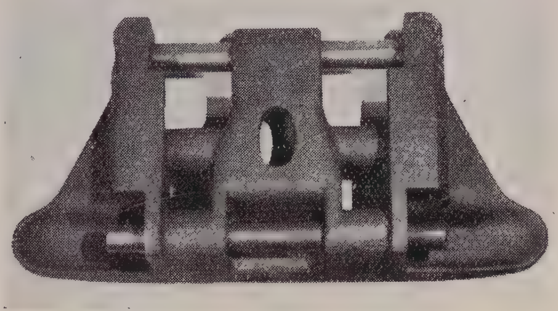

FIG. 2.—MANGANESE STEEL TRACK LINK. BACK VIEW.

The founding properties of the metal are good and, so far as relative fluidity and "life" are concerned, manganese steel more nearly resembles grey cast iron than carbon steel. In the particular casting under consideration, it was not found necessary to make any special provision for feeding.

The Casting

The casting which these plants were originally laid down to make is shown in Figs. 1 and 2. It is a simple form of tank track link (since superseded) for a heavy tank. The main dimensional tolerances are ± 0.010 in. The most important parts of the casting with respect to dimensions are the spindle holes, these having to be parallel in both planes within 0.030 in. in a length of 15 in. The tolerance allowed on the diameter of these holes is 0.020 in.

In Figs. 1 and 2 the spindles can be seen in the brackets which hold them. Three brackets are provided at the one end of the link, and this will in future be referred to as the three-lug end. These three lugs mate into two lugs at the other side of the next link. The two-lug end of the casting, with the spindle running through, can be clearly seen in Fig. 2.

Running and Gating

Some difficulties were experienced in deciding on the most satisfactory method of running and gating the casting and it was actually necessary to proceed with the preliminary lay-outs of the new foundries before

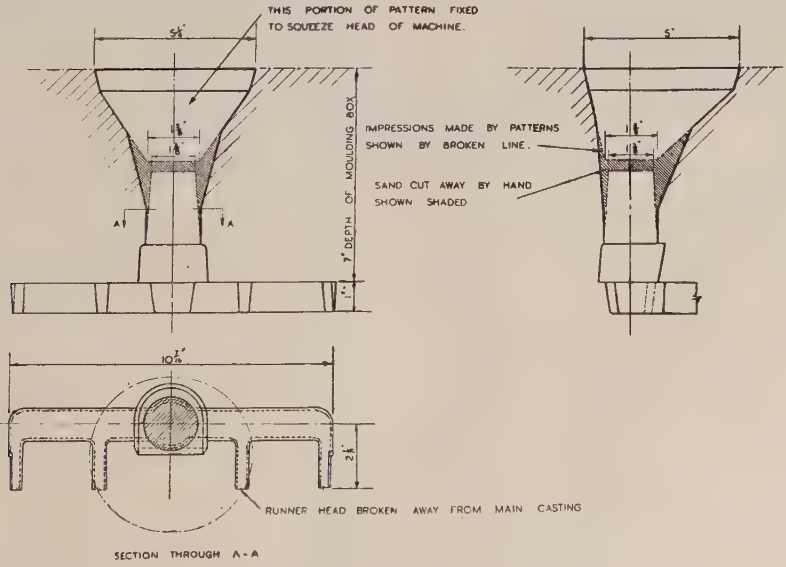
THIS PORTION OF PATTERN FIXED TO SQUEEZE HEAD OF MACHINE.
5½"
1⅜"
1⅛"
A
A
7" DEPTH OF MOULDING BOX
1"
5"
1⅜"
1⅛"
IMPRESSIONS MADE BY PATTERNS SHOWN BY BROKEN LINE.
SAND CUT AWAY BY HAND SHOWN SHADED
10 7/16"
2⅜"
RUNNER HEAD BROKEN AWAY FROM MAIN CASTING
SECTION THROUGH A-A

FIG. 3.—METHOD OF RUNNING AND GATING TRACK LINK.

any knowledge was available on the amount of molten metal needed to pour the casting. A temporary wooden pattern was secured and experiments were carried out in the pilot plant, as soon as possible, to obtain this essential information. No small experimental furnace was available or obtainable at this time, and it was necessary to produce a heat of 2,000 to 2,400 lbs. of steel to pour, say, half-a-dozen castings for experimental purposes. As will be explained later, in these early days the whole of the labour in the plant was without previous experience of foundry work and liable to stampede to safety if a few spots of molten metal splashed on the concrete floor.

Due to inexperience, and the fact that small heats of steel were wanted only at infrequent intervals, the metal was often cold and of incorrect analysis. Under such conditions it is not easy to decide whether defects are due to metal temperature, composition, mould conditions or to the method of gating adopted. It was something of an achievement, therefore, when it was finally proved to the satisfaction of all concerned that the casting, which weighed approximately 50 lbs., could be successfully poured with 70 lbs. of metal. The method of running adopted is shown in Fig. 3, and a casting exactly as removed from the mould is illustrated in Fig. 4.

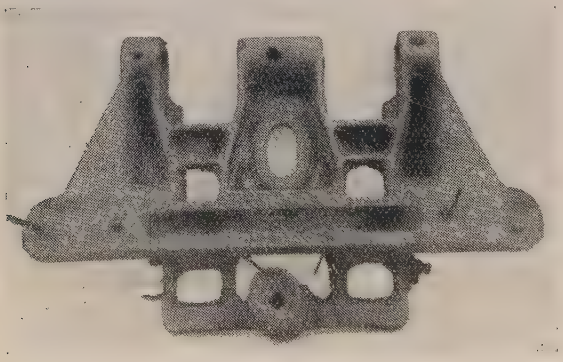

FIG. 4.—CASTING AS TAKEN FROM THE MOULD.

Lay-out of the Plant

The output required from the plant to be described was 360 tons of finished castings per month. The first item to be considered in the lay-out was the melting plant. Two methods are available for the production of manganese steel in the foundry. The basic electric furnace may be used to produce the steel direct from steel scrap and ferro-manganese, or mild steel may be made by the converter process from cupola-melted metal and the manganese steel made by mixing this with ferro-manganese melted in a separate furnace.

As has already been stated, the plant under consideration was changed over from the production of a mild-steel casting and the melting plant, consisting of cupolas and converters, had been installed. No experience was at this time available in this country on the mass production of manganese steel castings by any process, and although the converter process was in use for producing manganese steel, only an occasional heat, or at the most three or four heats a day were being made by this method. It was estimated that with the melting equipment available, approximately three heats each hour continuously for a nine-hour shift would be needed, that is, a total of 25 to 30 heats per shift. As far as could be ascertained at that time, no attempt had ever previously been made to produce manganese steel on such a scale by the cupola-converter process. In spite of this, and of the statement by Briggs[1]—that the basic electric furnace is indispensable in the manufacture of manganese steel, it was decided to proceed. In the entirely new plants, basic electric melting and holding furnaces were used, and it should perhaps be mentioned that the melting departments in these plants were not included in the sections designed and equipped by the author.

Another important point which had to be taken into consideration in connection with the design of the plant was the need for employing unskilled labour and, owing to the shortage of man-power, the necessity for making the maximum possible use of female labour. Of the labour force of 300 employed, the majority of which was obtained locally, less than 2 per cent. had had any previous experience of foundry work. Slightly over 50 per cent. were women and girls, of whom many had never previously done manual work. Because of this, it was necessary wherever possible to provide mechanical devices to lighten the heavier tasks and enable them to be carried out by women. The layout of the plant is shown in Fig. 5. The total floor area available of approximately 32,000 sq. ft., is allocated as shown in Table I.

TABLE I.—*Allocation of Floor Area for Various Sections.*

	Ft.	Sq. ft.
Core-making	95 × 42	4,000
Sand preparation, moulding and casting	145 × 50	7,250
Stock bins and melting	148 × 45 158 × 23	10,300
Fettling	75 × 50	3,750
Heat-treatment	85 × 50	4,250
Finishing and inspection	30 × 46	1,400
Despatch	22 × 46	1,000
		31,950

Molten metal from a cupola is supplied to a side blown converter and the ferro-manganese is melted in a small cupola or cupolette. No holding furnace is employed, so that the metal becomes available in batches approximately three times in the hour. For this reason a power-driven mould conveyor is not used. Moulding is continuous, the moulds produced on the two pairs of moulding machines being stored on horizontal roller track. When a batch of metal is delivered to the pouring station, the moulds are pushed along the conveyor by hand for pouring. Further storage capacity is provided between the pouring station and the shake-out to allow time for cooling, and this also enables the shake-out to operate continuously.

From the shake-out, the castings are loaded on to an overhead cooling conveyor which transports them to the fettling section. Here the runners and gates are removed and the castings are roughly inspected, any that are obviously defective being scrapped. A moderate amount of rough grinding can also be carried out. The castings are then heat-treated, finally inspected and assembled.

It is only to be expected that some difficulties will arise when starting up a new plant with entirely inexperienced labour, to mass produce a casting in a metal never previously used in quantity production. While it is not possible in a single paper to discuss all these difficulties in detail, it is hoped to outline some of the more interesting and important of these and the methods finally adopted. That these methods have been successful may be judged from the fact that the plant which was designed for an output of 360 tons has actually produced 550-600 tons of finished castings monthly on single shift working.

PRODUCING THE MANGANESE STEEL

The Cupolas

Three cupolas are used for supplying metal to the converters. One is used on each shift, while another is being repaired for the next shift. The provision of a third furnace enables major repairs, such as relining, to be carried out without interference with production. The furnaces have a 4 ft. 6 in. dia. shell, and are lined to 33 in. bore. They are of conventional design, equipped with one row of tuyeres, the only special feature in their construction being a boshed hearth below the tuyeres to increase the holding capacity for molten metal.

The charges used contain 75 to 80 per cent. steel scrap and a melting rate of 4.5 tons per hour is obtained. The metal charges are 700 lbs., made up as follows:—Carbon steel scrap, 460 lbs.; pig iron (0.05 per cent. P max.), 180 lbs.; manganese steel scrap, 60 lbs.; ferro-silicon (80 per cent. Si), 15 to 18 lbs. The actual amount of ferro-silicon charged depends on the silicon content of the pig iron, which varies from 1.4 to 2.0 per cent. Si. The coke charges are 90 lbs. and a limestone charge of 25 lbs. is put on with every metal charge. The hearth, when full to the level of the slag hole, holds approximately 2,800 lb. of metal, which is equivalent to four cupola charges. This is the amount of metal normally required as a charge for the converter. Due to wear on the converter lining, the amount of metal required for a charge varies, being lowest when a new lining is used and highest when the lining is nearing the end of its useful life. It is not always possible, therefore, to take exactly four cupola charges for a converter heat, and the amount required varies between extremes of 3½ and 5 charges. More than one tap is necessary when the converter charge exceeds 2,800 lbs.

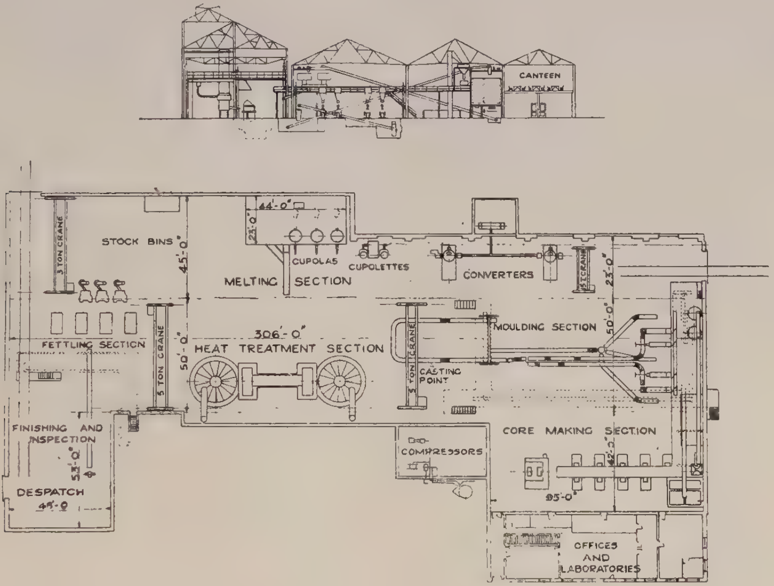

FIG. 5.—LAYOUT OF FOUNDRY FOR MASS-PRODUCING THE TRACK LINK.

Some authorities maintain that to secure metal of uniform analysis it is necessary that only complete charges shall be tapped from the cupola. This question has been carefully investigated, and it has been found that within the limits given above, metal of constant composition can be obtained, irrespective of the amount of metal drawn. The fact that a part only of a charge may be melted when a tap is taken does not cause any noticeable fluctuation in the composition of the iron.

The composition of the metal produced from the cupola is as follows:—Total carbon, 2.9 to 3.1 per cent.; silicon, 1.5 to 1.7 per cent.; manganese, 0.7 to 0.9 per cent.; and phosphorus, 0.06 per cent. max. No attempt is made to control the carbon content, as within the limits normally obtained, the influence of this element on the behaviour of the metal during its conversion to steel is negligible. The sulphur content, likewise, is unimportant, as a very large proportion of the sulphur is removed when the molten ferro-manganese is added to the steel. With a sulphur content of 0.09 per cent., in the cupola metal, the sulphur content of the manganese steel does not exceed 0.03 per cent.

At one time it was thought that a high sulphur content in the converter steel might produce inclusions in the finished manganese steel, and the effect of desulphurising the cupola metal was studied. As far as could be ascertained from microscopic examination, no improvement resulted and the amount of sulphur remaining in the manganese steel was not affected by this treatment. The manganese content of the cupola metal is not allowed appreciably to exceed 1 per cent., as high manganese results in increased wear on the converter lining and the production of a thin " sloppy " slag which is difficult to control. With a view to utilising more manganese scrap in the cupola charge, higher manganese contents have been tried, but on the whole it has been found advisable to restrict this element to a maximum of 1 per cent. for the reasons given above.

The whole of the phosphorus present in the cupola metal is retained in the finished steel. This element is also present in the ferro-manganese and in order to meet the specification of 0.10 per cent. P maximum, it is important that the phosphorus content of the cupola metal should not at any time exceed 0.06 per cent. This question is discussed further at a later stage, when casting defects are considered.

The most important element in controlling the conversion of the cupola metal to steel is the silicon content. This element is rigidly controlled, because on it depends not only the temperature of the finished steel, but also the time required for the conversion process. In the first few charges at the beginning of a shift, a silicon content of 1.7 per cent. is desirable, and this provides a little additional heat which counteracts the effect of a relatively cool converter lining. As soon as the lining reaches a suitably high temperature, the silicon content of the cupola metal is reduced to 1.5 per cent. This gives more rapid converter heats than is provided with a higher silicon content and enables metal of adequate temperature to be delivered for pouring at suitably short intervals.

The Converters

The converters are of the conventional Tropenas side-blown type and have a nominal capacity of 2,700 lbs. A converter body is used for one week, that is, for an average of 170 to 180 heats, and it is then removed for relining. A certain amount of lining repair is carried out between shifts, but this consists chiefly of repairs to the mouth of the vessel. Small hollows which may develop in the body opposite the tuyeres are filled with ganister, but these patches are not always successful, and it is found that the most satisfactory results are obtained by relining as soon as the condition of the lining warrants it, rather than by trying to prolong its life by patching. A spare shell ready lined is always available for use in an emergency.

With this method of operation, the holding capacity of the converter, as already mentioned, increases slightly from the beginning to the end of its life. This is a disadvantage, as for the most successful operation of the plant a regular supply of a definite quantity of molten metal is desirable. However, the most important point is that the weight of steel in the converter shall be known in advance within very close limits. Unless this can be accurately forecast, there is a danger that the quantities of steel and molten ferro-manganese mixed together will be outside the limits capable of yielding a manganese steel of suitable analysis.

By careful control of cupola operation, thus ensuring the provision of uniformly hot metal of regular composition, losses during the production of the steel are kept fairly constant and actually average about 12½ per cent. The weight of the molten cupola metal supplied to the converter is carefully checked by means of a dial type weigher on the crane, and it is thus possible to estimate with some certainty the amount of liquid steel which will be available.

Melting the Ferro-Manganese

The ferro-manganese is melted in a small cupola, sometimes known as a cupolette. The main details of this furnace are given in Table II. It will be seen that the shell diameter is 33 in., with an internal bore at the tuyeres of 21 in. The short preheating space above the top of the bed coke, coupled with the small tuyere area, enables the required melting rate of 1,350 to 1,650 lbs. per hour to be obtained without difficulty. Hot metal of uniform analysis is obtained and the loss of manganese during melting is only 6.5 per cent., that is to say, ferro-manganese with an average manganese content of 80 per cent. when charged contains 75 per cent. manganese after melting.

TABLE II.—*Details of Cupolette for Melting Ferro-Manganese.*

Shell diameter (external)	33 in.
Internal diameter of lining at tuyeres..	21 in.
Internal diameter of lining at top of stack	23 in.
Height from base plate to tuyere centres	2 ft.
Height from tuyere centres to top of stack	4 ft. 6 in.
Number of tuyeres	2
Size of tuyeres (include lining).. ..	3 in. by 3 in.
Height of coke bed above tuyeres ..	24 in.
Weight of metal charges	100 lb. approx.
Weight of coke charges..	12 lb. approx.
Blast pressure (taken at tuyeres) ..	8 in. W.G.
Number of charges to fill furnace ..	7
Holding capacity of well when full to slag hole	550—600 lb.

The lining of the cupolettes consists of one course of 4½-in bricks, with a facing of 1 in. of ganister in the well and tuyere zone. Spare shells are available and these are changed after each shift, a spare shell being kept ready for use in case of emergency. The lining in the melting zone for a height of about 2 ft. 6 in. above the tuyeres wears very thin towards the end of a shift and the brickwork in this zone is replaced before the furnace is used again.

A free-running slag is produced without the use of limestone or any other flux and is tapped off at approximately half-hourly intervals. This slag contains approximately 50 per cent. MnO and its average analysis is:—SiO_2, 30.0 per cent.; MnO, 52.0; FeO, trace; Al_2O_3, 15.0; CaO, 2.5; and MgO, 0.5.

The successful operation of the cupolette depends on the charging of coke and metal of a suitable and uniform size and in maintaining, as far as possible, a continuous blast throughout the shift. Bridging or hanging of the charges must be avoided as this leads to fluctuating metal temperature, variable melting losses and severe lining wear. In order to ensure that the charges melt regularly, all coke and the ferro-manganese is broken into pieces approximately 4 in. cube. Molten ferro-manganese at the temperature at which it is tapped from the cupolette has a very short " life," and it is for this reason that it is necessary to maintain the blast throughout the shift. If it is necessary to shut off the blast for periods of more than 20 to 30 mins., there is a danger that the metal will solidify on the working bottom of the furnace, making it difficult to re-open the tap hole when melting is resumed.

Mixing the Manganese Steel

It is not proposed to describe the steel-making process in the converter, and it will suffice to say that the converter is turned down when the flame indicates that the carbon content of the metal is below 0.10 per cent. An addition of ferro-silicon (80 per cent. Si) is then made to deoxidise the bath and to bring the silicon content up to the desired figure. The amount added varies from 20 to 25 lbs., according to the amount of metal in the converter. Fairly large lumps are used, and these are dipped in water before being thrown into the vessel. A mild explosion occurs when the moisture comes in contact with the slag covering, and this ensures that the addition comes in contact with, and is taken up in, the metal. The bath is then rabbled and an addition of 3 lbs. of aluminium is made as a safeguard to ensure complete deoxidation. The aluminium is fastened on the end of an iron bar and pushed well under the surface of the metal.

While these operations are being carried out, the required quantity of ferro-manganese, usually about 550 lbs., is being tapped from the cupolette. This metal is tapped into a small ladle suspended from the overhead crane, and the weight of the ferro-manganese can be roughly checked on the dial type weigher used on this crane. This is not, however, sufficiently accurate for a final weighing, and the ladle containing the molten metal is transferred to a weighbridge as a check. The molten ferro-manganese is then poured into the large ladle used for mixing and pouring the steel. The empty ferro-manganese ladle is put back on the weighbridge and weighed again. This is a final check on the weight of ferro-manganese put into the steel ladle, and is necessary because occasionally a skull is left by the ferro-manganese. All these operations may sound a little complicated, and some may appear redundant, but experience has shown the necessity for each check if heats of correct analysis are to be produced.

The ferro-manganese cannot be tapped immediately into the steel ladle because this is too large to be weighed accurately on the weighbridge. Further, if the amount tapped is too great, it is much more difficult to pour a few pounds into a pig mould from a large ladle than from the small one. Because of the short life of the metal, it tends to solidify if poured in a thin stream up the wall of a large ladle, and under these conditions it is not easy to judge the amount poured down.

The aim in this part of the process is to tap exactly the amount of ferro-manganese required by the molten steel in the converter. As already described, the quantity of steel available is known within fairly narrow limits, and molten ferro-manganese is needed in the ratio of 1 lb. of ferro-manganese to 4.5 lbs. of steel. If too much ferro-manganese is tapped, there is no special difficulty in pigging a small quantity. On the other hand, if the amount of ferro-manganese is found, after weighing, to be insufficient, three courses of action are open. Sometimes the deficiency can be made good with solid cold ferro-manganese. There is, however, a limit to the amount of solid material which may be used, on account of its chilling action on the steel, and the absolute limit of cold metal is 20 to 30 lbs. If red hot ferro-manganese, pigged on a previous heat, is available, up to 56 lbs. may be added in an emergency.

If, due to some mistake in the preliminary weighing on the crane, more than this quantity is required, it is sometimes possible to take the ladle back to the cupolette for more metal. Should there be insufficient time for this as, for example, when a skull is left in the ferro-manganese ladle, then a new calculation must be made and the amount of converter steel used must be based on the amount of ferro-manganese available. This practice is avoided as far as possible, partly because of the difficulty of obtaining a correct reading on the dial weigher suspended above the steel ladle while the steel is being teemed and because of the difficulty of stopping the pouring from the converter at the correct point. Moreover, the unwanted steel in the converted must be teemed into another ladle and pigged. This is an additional operation for which time is not really available, and it tends to slow up the production of the next heat of steel.

When the ferro-manganese has been transferred to the steel ladle, this is taken to the converter and the correct quantity of steel teemed into it on top of the ferro-manganese. Slag is prevented from entering the steel ladle by a refractory brick held in position across the mouth of the converter, which acts as a skimmer. Any steel remaining in the converter after the required amount has been taken for the manganese steel is then teemed and pigged. In normal practice it is, however, exceptional for this to be necessary. The converter is inverted to remove the slag and is then ready to receive the next heat. Table III shows a typical melting record with times for the various operations.

When the molten steel is poured on to the molten ferro-manganese, an almost completely homogeneous mixture of the two constituents results. Numerous analyses taken on metal poured at various intervals while a ladle is being emptied have shown that variations in carbon content do not exceed ± 0.05 per cent. and variations in manganese are less than ±0.50 per cent. An interesting point is that no matter how completely the converter steel is deoxidised, there is a loss of manganese which apparently occurs as the molten steel mixes with the ferro-manganese. This loss is practically constant and is equivalent to approximately 3 per cent. of the manganese added. That is to say, the manganese content of the finished steel is approximately 0.5 per cent. lower than would be expected by calculation. A heavy manganese loss occurs if the converter slag comes into contact with the ferro-manganese, and this question will be examined more closely in the next section.

Initial Difficulties in the Melting Section

Many of the difficulties experienced in putting the melting section into successful operation were due to cold metal. This was to some extent unavoidable as, owing to the inexperience of the moulding machine operators, mould production was slow and heats were at first required at intervals of up to 1 hr. Under these conditions the converter, which at that time was lined down to reduce its output and had a lining 24 in. thick, was never really hot. Even if a start were made with a hot lining, it had ample time to cool down between heats.

Because of the low rate of melting required from the cupola, but with the necessity for taking relatively heavy taps, it was not easy to secure hot metal, and the same conditions applied on the cupolette. Experience has since shown the absolute necessity for the hottest possible metal from the cupola, coupled with a continuous series of heats from the converter, if trouble-free operation is to be secured.

The lining of the converter is raised to a good white heat by means of a coke fire using the ordinary air supply through the tuyeres, before the first heat of the day is put in. After this the heats follow in such rapid sequence in the normal operation that the lining is kept hot. If an enforced shut-down occurs in the melting shop, coke is put into the vessel and blown with a gentle air blast until work can be resumed. This practice is also followed during the mid-day break. For the same reason it has been found essential to use ladle heating equipment which gives a really hot lining. For this purpose, high-pressure air and gas burners are used and all steel and ferro-manganese ladles are strongly heated before use.

Table III.—*Melting Record of Typical Heat of Manganese Steel.*

Heat 8—	
Cupola tapped	10.10 a.m.
Weight of cupola metal tapped ..	2,750 lb.
Metal in converter	10.20 a.m.
Blast on converter	10.21 a.m.
Ferro-manganese tapped	10.28 a.m.
Weight of ferro-manganese tapped ..	530 lb.
Ferro-manganese transferred to mixing ladle	10.32 a.m.
Converter blow finished, blast off ..	10.33 a.m.
Additions made to converter—	
Ferro-silicon, 80 per cent. Si ..	25 lb.
Aluminium	3 lb.
Converter metal poured into mixing ladle	10.35 a.m.
Weight of manganese steel	2,940 lb.
Manganese steel ready for pouring ..	10.40 a.m.
Analysis manganese steel—	
Manganese	13.2 per cent.
Carbon	1.26 ,, ,,
Heat 9—	
Cupola tapped	10.30 a.m.
Weight of cupola metal tapped ..	2,750 lb.
Metal in converter	10.39 a.m.
Blast on converter	10.40 a.m.

Some difficulties were also experienced with the method originally used for mixing the manganese steel. At that time it was suggested that in order to obtain a completely homogeneous steel, it was necessary to pour the ferro-manganese into the molten steel in the converter. The ferro-manganese ladle had then to be washed out with some liquid steel from the vessel and this again poured back. The vessel was then rocked once or twice thoroughly to mix the contents and the steel was then teemed into the pouring ladle. It was held by authorities using this method of mixing that if the steel were added to the ferro-manganese in the ladle, there might be occasional heats when a good mixture would not be obtained and castings would vary considerably in analysis, with the possibility that some would be outside the analytical specification.

This method of mixing was used for some time, and it was found that unless a large proportion of the converter slag was removed before the addition of the molten ferro-manganese, a heavy loss of manganese occurred without a corresponding loss in carbon. As mentioned earlier in this Paper, in the most satisfactory manganese steel, the carbon content should be not more than, and preferably a little less than, one-tenth of the manganese content. Thus a steel with a manganese content of 13 per cent. would be expected to have a carbon content of 1.25 to 1.30 per cent. If some slag were left on the surface of the converter metal and sufficient ferro-manganese were added to yield 13 per cent. manganese in the finished steel, it was found that a carbon of 1.25 to 1.30 per cent. resulted, but with a manganese of, say, 11.0 per cent. Such steel is more difficult to heat-treat successfully than those in which the manganese and carbon contents are in the ratio given above. Completely removing the slag was found to be a very tedious and strenuous task when this had to be done three times in the hour, and it was almost impossible to ensure that the operation was carried out satisfactorily on every heat.

Other unsatisfactory features were the time taken in this method of mixing and the fact that the manganese steel had a pronounced erosive action on the converter lining, necessitating heavy patching after every shift. It was therefore a most satisfactory solution to a number of difficulties when the present method of mixing was found consistently to yield a homogeneous and uniform steel.

Lining Wear

Lining wear in the cupolas, cupolettes and converters was the cause of some trouble in the first few months. The cupolas, with a lining of 10½ in. of brickwork, have to melt charges containing 75 to 80 per cent. steel scrap for 9-hr. heats. As would be expected, the wear on the linings was heavy and frequent renewal was necessary. The charges used on the cupola did not contain any silica; the steel scrap was, of course, free from sand, and even the pig-iron was machine cast. Some reduction in lining wear has been obtained by charging a quantity of siliceous material into the cupola. Ordinary silica sand was at first tried, but it was found that a large proportion of this was lost by being blown out of the stack. The present method is to use a charge of 7 to 10 lbs. of sandstone with each metal charge. The actual amount used depends on the nature of the stone, as it is found that some is more efficient than others.

The linings of the cupolettes gave some anxiety at one period, and it was a common occurrence for a part of the shell to become overheated before the end of the shift. The possibility of having to instal larger shells with a thicker lining was considered, but it was decided that if at all possible this should be avoided, owing to the greater cooling effect a thick lining would have in the early stages of the heat. As already stated, ferro-manganese has a short " life," and there is a great tendency for it to chill in the bottom of the furnace.

A small amount of limestone was originally used as a flux, and when it was found that this could be dispensed with, some reduction in lining wear resulted. Further considerable improvements were effected by breaking up all metal and coke to a small, uniform size, thus preventing hanging and bridging of the charges. Keeping the furnace full to the top of the stack was also found of considerable importance in avoiding lining wear, as was also maintaining a constant air supply throughout the shift. When the cupolette had to melt for 60 min. in the hour instead of the blast being on for only 40 min., a noticeable improvement in lining life resulted.

The bricks used in the lining are a high quality firebrick containing 40 to 42 per cent. alumina, and these now give very satisfactory results. It is quite possible that a basic lining is the final answer to the problem of lining erosion in the cupolette. This has been considered and a lining of magnesite brick was used, but serious difficulties were encountered in producing a suitable slag, and there was a marked tendency for the furnace to bridge over at the tuyeres. Mainly because magnesite and other suitable basic refractories were in shorter supply than firebrick, no further attempts were made to employ them. It is of interest to note, however, that when the magnesite brick lining was used, it was found that erosion was negligible after eight hours' melting.

Mention has already been made of the reduction in lining wear in the converter when the manganese steel was mixed in the ladle instead of in the vessel. Lining wear cannot now be considered a serious problem, and the capacity of the vessel normally increases from about 2,650 lbs. at the beginning of the week to about 3,500 lbs. at the end. As a week's work usually involves over 160 heats and no internal patching is normally carried out, it is considered that lining life is generally satisfactory. A further reduction in lining erosion has been secured by the use of a sand addition to the converter. About 40 lbs. of sharp silica sand is thrown into the vessel after the slag has been drained at the end of every heat. Some of this sand frits on to the lining and helps in reducing the total wear.

The effect of leaving slag from a previous heat in the converter was studied, and this was found to have a very serious erosive action on the lining. When discussing the mixing of the manganese steel it was pointed out that if any metal is left in the converter, this has to be poured into pigs. It was thought at one time that this operation could be avoided if the steel were left in the vessel as part of the next charge. Unfortunately, the major part of the slag covering has also to be left in, as it is too viscous to be poured off without also losing the steel, and the only alternative being to remove it with rakes, which is a very strenuous and exhausting process. The slag was therefore left in the converter with the excess steel, and while it had no noticeable effect on the steel-making process, apart from causing a greater amount of projections from the vessel, lining life was reduced by a half, and this method of working had to be abandoned.

Ladles

When the first heats of manganese steel were made in the new foundry, bottom pouring ladles were used, of the type often employed for pouring steel castings. The ladles were lined with firebrick tiles with a facing of ganister. The stoppers and nozzles were of standard firebrick material. It was found that the erosive action of the steel on the stoppers and nozzles was so severe that it was impossible successfully to pour the number of castings required. A change was therefore made to lip pouring ladles.

From the experience gained with the bottom pouring ladle, there appears to be good ground for believing that when a large number of castings has to be produced from one ladle of metal, to very close dimensional tolerances, lip pouring will produce castings more true to size than bottom pouring. It is believed that when bottom pouring from a full ladle, the pressure of the metal will cause swells sufficient to cause trouble in the assembly of the castings.

Ganister and firebrick lined lip pouring ladles were used for a time, but very serious trouble was encountered due to a thin fluid slag which was continuously produced by the action of the metal on the acid lining. It was almost impossible to prevent this slag from being carried over into the mould with the metal, and rejection of castings due to slag inclusions was high. Erosion of the lining was so severe that a ladle could be used only for two or at the most three heats and then had to be relined. A change was therefore made to a chammotte lining.

The chammotte used contained a high alumina grog and a lining 3 to 4 in. thick was rammed up on top of firebrick tiles. This material was a very considerable improvement on the ganister lining, for length of service and the amount of slag produced during pouring, but it still suffered from the same disadvantages. Slag was still produced the whole of the time the metal was in the ladle and was of such a thin, fluid nature that it could not be prevented from entering the moulds. Various types of skimming devices were tried, without success. Acid refractory skimmers eroded away and produced more slag, which immediately ran into the moulds; basic refractories spalled and washed and were of little assistance.

A noteworthy point in connection with the use of ganister and chammotte ladle linings for manganese steel is that the reaction resulting in the production of the slag also results in a silicon pick-up by the manganese steel. Analyses taken on the first metal poured from a ladle showed a silicon content of about 0.3 per cent. and this was found to increase progressively until the last castings contained 0.9 to 1.0 per cent. silicon. The average pick-up of this element while pouring a ladle of 2,800 lbs. of steel was of the order of 0.5 per cent.

Finally, a change was made to a new material specially developed for manganese steel ladles then in use at Hadfields, Limited, Sheffield, the originators of manganese steel. This is a basic monolithic lining material known as Dolocrete, which is available in two grades, one for ramming up the ladle and the other for patching and repairs. Dolocrete is mixed with water and a little linseed oil and must be used immediately it has been prepared, as it dehydrates rapidly. To obtain the best results it should be rammed round a former and the harder the ramming, the better the life of the lining.

The lining must be well vented and drying in the first stages must be slow and uniform. At the beginning of this operation, the lining softens, and for this reason the ladle cannot be inverted. When the lining has become thoroughly hard, the ladle is inverted over a gas burner and the lining strongly heated before use. The average life of a ladle lined in this way is 25 to 30 heats. Although the Dolocrete lining is fairly robust, it is important that skulls should be avoided as far as possible, as serious damage to the lining may result from attempts to remove the heavy skull. Patching is necessary at intervals, especially round the pouring lip, but this is due to mechanical damage rather than erosion of the lining.

With a Dolocrete lining, the difficulty of thickening up the slag is completely overcome. Some slag collects on top of the metal when the steel and ferromanganese are mixed, and some of this mav. of course, have passed over from the converter. This slag is thickened with a little silica sand and is raked off. A little Dolocrete is then sprinkled on top of the metal and this converts any slag remaining into a hard crust. No further slag is produced while the steel is being poured, and one man, using a bent iron bar, effectively prevents any slag from entering the moulds. The total loss due to slag inclusions is less than 0.4 per cent. and is not considered excessive when lip pouring an average of 40 moulds from each ladle.

When the change-over was made to the Dolocrete ladle, no pick-up of silicon was obtained, and it was found that the fluidity of the steel diminished slightly. This is the reason a ferro-silicon addition is made to the converter to bring the silicon content to a figure of about 0.8 per cent.

One further point which may be of interest is that the heat radiated from the large open ladle was found to be rather trying for the operator who holds back the slag on the ladle. A mask consisting of fine mesh wire gauge was developed. This is fastened round the head and hangs loosely in front of the face and not only absorbs most of the radiated heat, but has prevented numerous small burns from metal splashes.

THE MOULDING SECTION

Moulding Sand

Reference to the lay-out of the moulding section in Fig. 5 shows that the sand is delivered from the main storage hoppers by a belt conveyor to two mills of the Simpson batch type. The mills are fed alternately and the sand is discharged without further treatment from both mills into a hopper. From here it is fed to the moulding machine hoppers, by another belt conveyor, at the same rate as it is produced, and in this way a continuous supply of sand is obtained. Batch mills were installed in preference to a continuous mill, as it was considered that this would allow greater variation of milling time than could be secured with a continuous unit.

The sand used is a fairly coarsely graded sharp silica sand with the following approximate mechanical analysis:—Remaining on British Standard Sieve No. 16, 0.5 per cent.; No. 30, 25.0 per cent.; No. 44, 55.0 per cent.; No. 60, 16.0 per cent.; No. 100, 3.0 per cent.; No. 150, 0.5 per cent. This is bonded with a colloidal clay known as Colbond. The green strength obtained with this clay is about 50 per cent. that obtained by the use of a similar quantity of bentonite and the dry strength is less than that yielded by a bentonite addition giving the same green strength. The clay content of the sand is maintained at approximately 8 per cent.

Sand control has been found of paramount importance in securing trouble-free operation and the avoidance of casting defects of various types. Routine determinations of green strength, permeability and moisture are taken continuously throughout the shift and the properties are kept within the following range:—Green strength, 9 to 11 lbs. per sq. in.; permeability, 130-150; and moisture, 3.9 to 4.3 per cent. A shatter test is also employed and has been found a most useful index of the moulding properties of the sand. For this test, a standard A.F.A. test core is dropped from a height of 6 ft. on to a steel plate. The shattered core is placed on a ½-in. mesh wire screen and that remaining on the screen is weighed.* The weight in grammes is reported as a "plasticity" figure. It has been found that under the conditions of operation in this plant, and with a green strength in the range given above, a plasticity of 120-135 should be maintained. If the plasticity figure falls below 120, trouble is experienced from moulds becoming broken after closing, either before or during casting, and with a figure of more than 135 there is a tendency towards the production of hot tears in the castings.

One further test which has been found of considerable value is the mould hardness test. Too great a ramming density has also been found to increase the possibility of hot tears developing in the castings, and tests are therefore taken at frequent intervals to ensure that the hardness of the mould face does not exceed

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* Recommended by John J. Sheehan.

80 to 85. On the other hand, readings must average more than 70 to 75 if swollen castings are to be avoided.

The bond addition is made as the moulding sand is fed from the main storage hoppers to the mills. The Colbond is stored in a bin situated above the belt conveyor and is fed on to this by a rotary table. The layer of sand on the belt is opened and closed over the Colbond by ploughs, as it has been found that this prevents bond being lost as it falls with the sand into the mill. The weight of bond added is controlled by the time the table is allowed to rotate, as each individual batch of sand passes to the mill. The quantity added is, of course, varied to suit requirements, but is usually of the order of 5 lbs. in a batch of 600 lbs. of sand.

When a manganese steel casting is removed from the mould, a thin skin of fused sand grains is found adhering to it. An analysis of this slaggy material shows it to contain a considerable proportion of manganese, and it is probable that the fused material is a silicate of manganese. While the casting is hot, this fused sand is attached to it quite firmly, but fortunately when the full contraction of the metal is reached it falls away. The fused sand is not suitable for returning to the system, and it is removed by screens from the sand carried to the fettling shop and dumped. Each casting poured thus represents a certain loss of sand, and it was decided that the weight of the new sand added should be based on the number of castings produced.

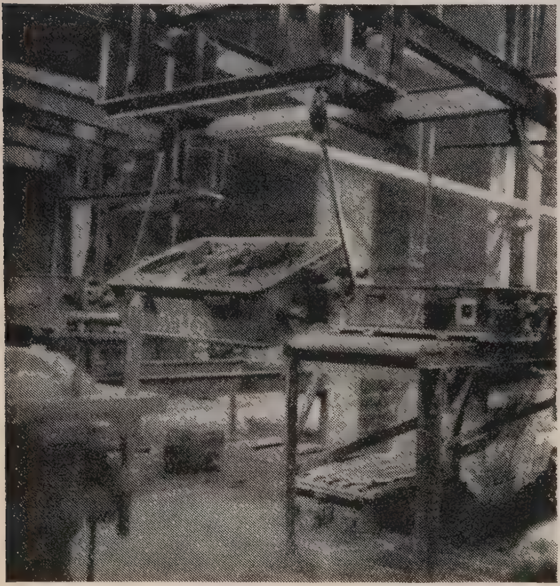

FIG. 6.—MOULD LIFT-OFF AND TURNOVER DEVICE.

In practice it has been found that a new sand addition of 5 lbs. per casting adequately covers all sand lost from the system. The new sand is therefore fed continuously from a separate bin at a rate of 5 lbs. for each mould produced. This sand enters the system on the conveyor, which carries the moulding sand from the shake-out to the main storage hoppers, and is not added to each batch of sand at the mills.

Moulding

The machines used are of the pneumatic, jolt-squeeze pin lift type, and are operated entirely by girls. Production averages 55 to 60 moulds per hr. from each pair of machines. Over 1,000 moulds are obtained per shift from the two pairs of machines installed. Wooden lifters are used in the deep pockets on either side of the link in the top part of the mould. These pockets can be clearly seen in Fig. 1. It has been found that when sand conditions are ideal, the lifters are unnecessary, but it is not possible to maintain these conditions continuously in practice and the lifters are therefore always used.

The weight of a half mould is 260 lbs., and it was impossible for girls to lift this weight unaided from the machines on to the roller track and at the same time secure the necessary production. A simple but effective mould lift-off and turnover device was therefore developed to reduce the physical effort involved. It consists of an overhead trolley fitted with hangers which locate in the trunnions of the moulding box. When the moulding machine lifting mechanism is retracted, the box is left suspended from the trolley, and can be turned over and transferred on to the conveyor with a minimum of effort. This device, which is used on each machine, is illustrated in Fig. 6.

The bottom and top parts of the mould are deposited on separate runs of roller track. The bottom part is transferred to a carriage fitted with rollers which which travel at right angles to the direction of travel of the carriage. While on the carriage, the mould is cored up and brought to the point where it is joined by the top part. The top part of the mould is raised by a small pneumatic hoist and lowered on to the bottom part. Pneumatic hoists were installed primarily because of the long delivery of electric hoists, but they have proved very satisfactory in operation, and enable closing to be carried out slowly and smoothly by girls.

The completed moulds are clamped and pushed down the roller track towards the pouring point, also by girls. Storage space is available for 60 moulds, and an average batch of metal will pour between 40 and 45 castings.

Core-Making

In the core-making section, only unskilled labour was available and, in fact, the making of the cores, inspection and setting in the moulds and the supervision of all this work had to be carried out by operatives without any previous foundry experience. Careful consideration was therefore given to the arrangement of the cores, and it was decided that a number of simple cores would be preferable to a few of a more complicated type. The set of twelve cores used is shown in Fig. 7, and these cores are made by hand at a rate of approximately 1,250 sets per shift by 30 unskilled girl coremakers. A further advantage of the simple cores is that they can be dried on flat plates without distortion.

The top part of the mould is shown in Fig. 8 and the bottom part in Fig. 9. The method of setting the cores is shown in Fig. 10. It should be particularly noted that a separate core is used for each spindle bracket. It is, of course, essential that the three spindle cores on the one side and the two on the other shall be completely in line. A tolerance of only 0.020 in. is allowed on these holes, and they must be parallel in both planes within ± 0.030 in. in a length of 15 in. At first sight, it may appear advantageous to use a single long core on either side, and this method was adopted in certain of the plants. The alternative arrangement of coring is shown in Figs. 11 and 12.

Experience has shown, however, that with unskilled labour, the simpler cores are easier to make and assemble without faults, and allow much more rapid production to be obtained. Each of the spindle cores is provided with a greensand register in the mould, and thus the correct location of these cores does not depend on the satisfactory setting of other cores. The greensand registers can be clearly seen in Fig. 9.

The sand used for the cores is a fine-grained silica sand containing about 2 per cent. of natural clay. The grading of this sand is as follows:—Remaining on British Standard Sieve No. 22, 0.6 per cent.; No. 30, 0.4 per cent.; No. 44, 1.2 per cent.; No. 60, 44.0 per cent.; No. 100, 38.0 per cent.; No. 120, 9.0 per cent.; No. 150, 5.5 per cent.; No. 200, 0.7 per cent.; No. 300, 0.6 per cent. It is mixed with 3 per cent. of a proprietary core binder and yields a core sand with a green bond of approximately 3 lbs. per sq. in. and a permeability of 80. An advantage from using this finely graded sand is that no wash is required and no trouble is experienced with metal penetration.

The handling and distribution of the core sand is carried out by conventional means. The sand is first passed through a drier and is then raised by a bucket elevator to a bin above the mixer, the latter being situated on a platform. A specially developed measuring device attached to the bin ensures that the correct quantity of sand is loaded into the mixer. The mixed sand is discharged into barrows and distributed in this way to the hoppers above the core-making tables. Bulk handling of the sand prevents air drying, and precautions are also taken to prevent drying of the sand on the tables. The bottom of the hoppers are provided with sliding gates which must be raised when a supply of sand is taken for use.

A vertical continuous stove is used for drying the cores and from this they are loaded into storage racks. From here the cores pass through inspection and are made up into sets for transporting to the moulding section.

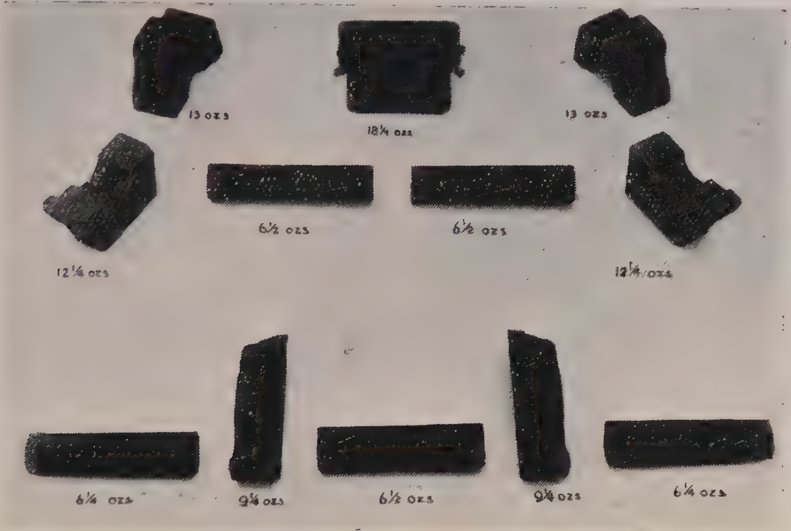

Fig. 7.—Cores Used for Track Link Casting.
Total Weight 7 lb. 7¼ oz.

The Shake-out

After pouring, the moulds are pushed round the roller track towards the shake-out. Storage capacity is provided to allow time for the castings to solidify and cool to a temperature where removal from the mould cannot cause damage. Because of its very low thermal conductivity, manganese steel cools slowly and at least 15 min. is allowed between pouring and shaking out. The shake-out used is illustrated in Fig. 13. It consists of a vibratory device attached to a pneumatic hoist, the whole being mounted on an overhead runway. The boxes are provided with bars and must therefore be shaken out in halves. With

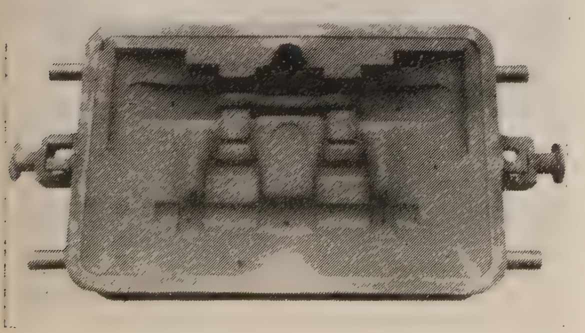

Fig. 8.—Top Part of Track Link Mould.

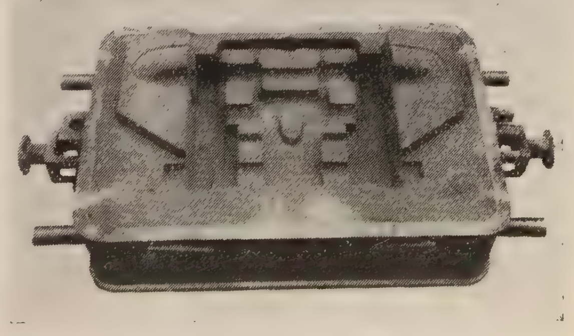

Fig. 9.—Bottom Part of Track Link Mould.

this device, one man can deal with over 1,000 moulds, that is 2,000 box parts, per shift.

The top part of the box is lifted by its trunnions and swung towards the shake-out grid. As it passes near the grid the vibrator is operated and the sand falls away. The box part is then deposited on an inclined roller track which returns it to the moulding stations. The vibratory device is then swung back and deals with the bottom part in the same way, except that the box is turned over as it is vibrated, to release the casting. The total time taken in the two operations is less than 20 secs.

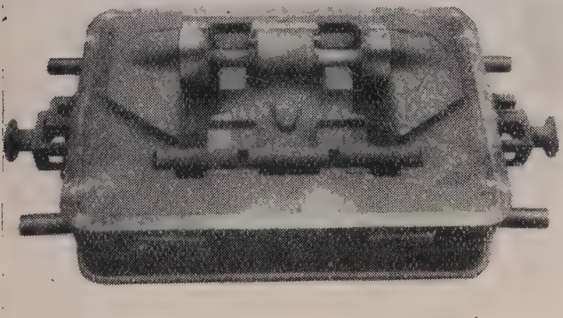

FIG. 10.—BOTTOM PART OF TRACK LINK MOULD SHOWING CORES IN POSITION.

The sand is not shaken out directly over the grid, but to one side of it. This is done for two reasons, the first being that unless the hot casting falls on to a deep cushion of sand, there is a danger that the spindle brackets may be knocked seriously out of alignment. The second reason is that the author considers it fundamentally wrong to supply sand on to a belt conveyor sporadically in large quantities. The conditions under which the shake-out belt operates are always severe, but wear and stretching are considerably increased if the sand is not fed at a fairly uniform rate. The used sand is therefore fed through the grid by shovels, and this method has the added advantage that any large pieces of metal spillage, flash, etc., which could cause serious damage to the belt are picked out.

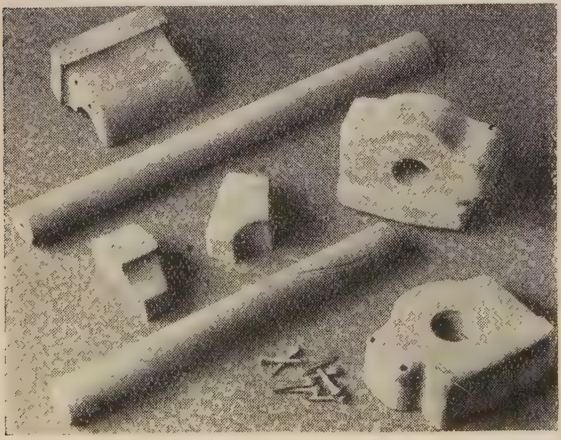

FIG. 11.—ALTERNATIVE ARRANGEMENT OF CORES FOR TRACK LINK.

An important point to be considered in a foundry making manganese steel castings is that metal flash, shot, etc., entering the sand is non-magnetic and cannot therefore be removed by magnetic means. Care is taken to see that all metal spillage on the top of the mould is scraped off before the box passes to the shake-out. Any of the larger pieces of metal are picked out when the sand is being thrown through the shake-out grid and two screens are installed in the system for further cleansing. The latter also tend to break down most of the unburnt cores. This core sand is allowed to enter the moulding sand and no attempt is made to reclaim it for use in the core mixture.

Starting up the Moulding Section

Perhaps the main difficulty experienced in this section was in securing the required production from the moulding machines. When work began, estimates of the ultimate mould production put forward by the foremen and operators varied between 10 and 20 moulds per hour. Production with new and completely inexperienced operators, as would be expected, was at first slow and this led to difficulties in the melting shop already mentioned. During this period it was not easy to maintain uniform sand conditions, as frequently very few moulds would be cast and unpoured boxes were shaken out. Unused sand passing back through the system often received additions of bond and moisture which were not required, with the result that the plasticity rose until it was impossible to produce a good mould. This was only remedied by making large additions of new sand.

It was found that when the strength of the sand, as indicated by the green compression test, rose above 12 lbs. per sq. in., the sand was discharged from the mills in hard lumps and so was not in a suitable condition to produce good moulds. This trouble was corrected by placing a definite upper limit on the green strength allowable.

The fact that metal shot and flash could not be removed from the sand by magnetic means was not discovered until the plant was in operation, and suitable screens were not immediately available. The metal content of the sand rose to somewhat alarming proportions, and it was at one time impossible to take up a handful of sand which did not contain a number of pieces of steel. Remarkably, this appeared to have no effect on the castings, apart from an occasional small surface blemish which could be removed in fettling, but it did begin to cause damage to the patterns, which were of aluminium. The installation

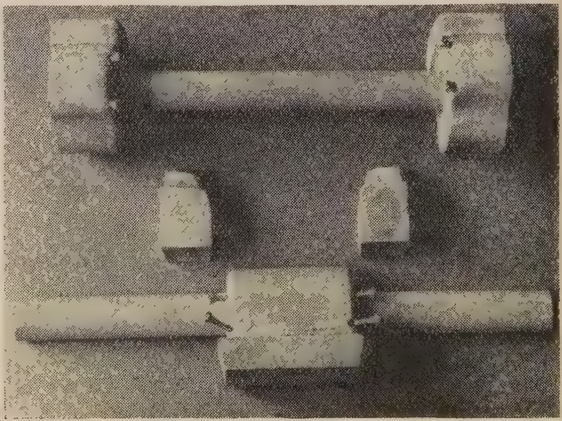

FIG. 12.—ASSEMBLY OF ALTERNATIVE CORE ARRANGEMENT.

of more and suitable screens completely overcame this particular problem.

Little trouble has been experienced due to the necessity for using hot sand which occurs when the plant has been in operation for 3 to 4 hrs. The sand finally reaches a temperature of about 100 deg. F. No provision had been made for heating the patterns, and for a time bad lifts were experienced when hot sand began to circulate. It was finally found that the use of a spray consisting of 50 per cent. paraffin (kerosene) and 50 per cent. linseed oil was of great assistance in preventing sand sticking to the pattern.

When the plant was first put into operation, the moulds were placed on wooden bottom boards on the roller track. These boards very quickly became damaged, and it was decided that the moulds must be poured without the use of boards. This led to a considerable rise in scrap due to broken moulds. Modifications were, however, made to the sand, to the degree of ramming and also to the method of handling the moulds on the track, wtih complete success, and it was unnecessary to replace the bottom boards.

FETTLING AND HEAT-TREATMENT

Fettling

From the shake-out the castings are transported by an overhead conveyor to the fettling section. Because of the low thermal conductivity of the metal, which causes cooling to be abnormally slow, it is necessary to arrange for accelerated cooling of the castings by means of water sprays, and this also assists in cleaning. On reaching this section, the castings are sufficiently cold to be handled, and the runner is broken off by a blow from a hammer. The portions of the gates which remain attached to the castings are also broken away. Any flash and sand remaining in the pockets is removed with pneumatic chipping hammers. After heat-treatment, the metal is very difficult to chip, so that all chipping must be carried out at this stage.

In the as-cast state the castings are relatively brittle, and although they will withstand fairly rough handling, there is a danger that this will start small cracks which will be opened up on heat-treatment. Suitable precautions are therefore taken to prevent the castings being excessively hammered, thrown about or dropped on to one another or on the floor. A rumbler of the wheelabrator type was installed for cleaning before inspection, but its use had to be abandoned when it was found that over 50 per cent. of the castings so treated showed hair cracks after heat-treatment.

Local overheating of the surface by heavy grinding also causes hair-cracking, and such grinding is therefore not permitted on unheat-treated castings. Where necessary, grinding is carried out as gently as possible after heat-treatment. After fettling, the castings are inspected and gauges are used to check up on overall dimensions. The total scrap at this stage averages approximately 2.5 per cent.

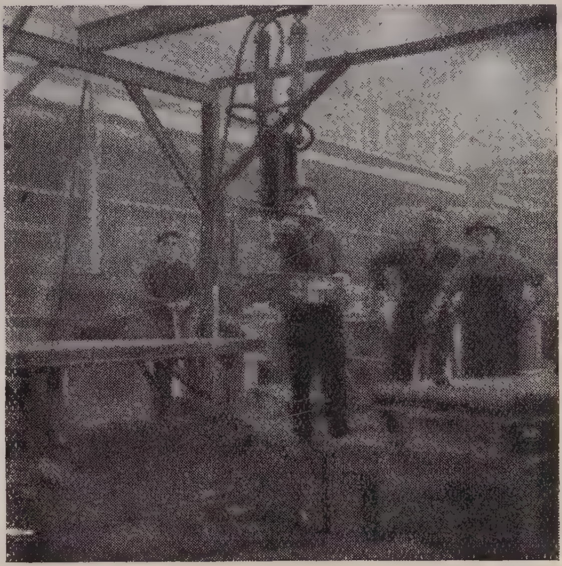

FIG. 13.—PNEUMATIC VIBRATORY SHAKE-OUT.

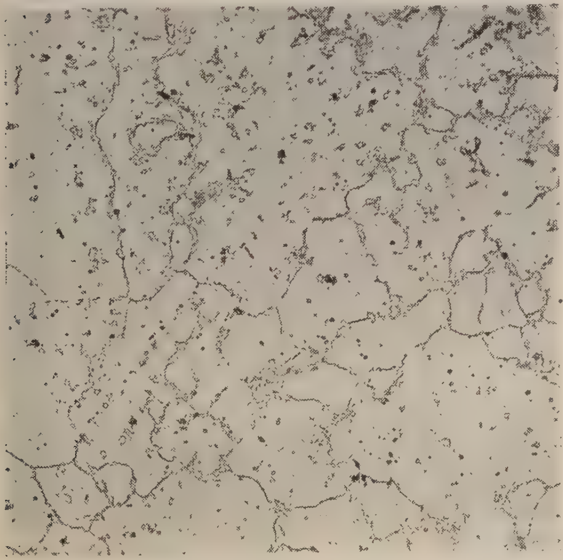

FIG. 14.—MANGANESE STEEL AS-CAST. ETCHED 2 PER CENT. NITAL, × 100 DIA.

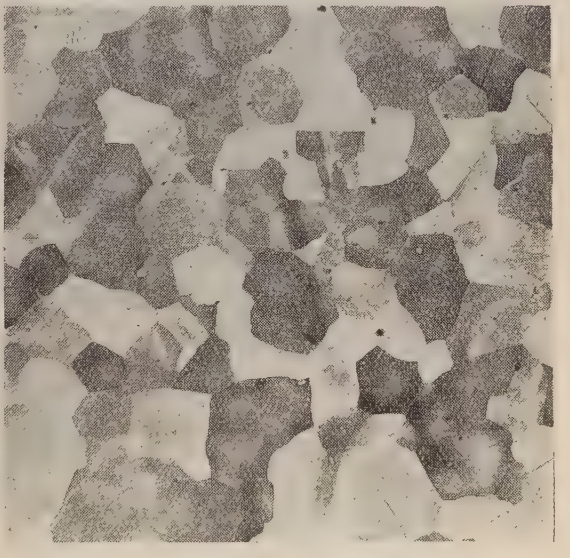

FIG. 15.—MANGANESE STEEL, WATER QUENCHED FROM 1.050 DEG. C. (1920 DEG. F.). ETCHED 2 PER CENT. NITAL, × 100 DIA.

Heat-Treatment

In order to obtain the maximum ductility and strength from manganese steel it is necessary to soak the castings at a temperature of 1,000 to 1,100 deg. C. (1,830 to 2,010 deg. F.) and quench in water from this temperature. The carbon content of the steel may be between 1.0 per cent. and 1.4 per cent., and in the as-cast condition some of this carbon exists as free carbides in the form of small lakes arranged as a network. This is the reason for the relative brittleness of the unheat-treated steel. The object of the heat-treatment is to take these free carbides into solution and retain them in solution by quenching. If the heat-treatment cycle is correct, a wholly austenitic structure should be produced. Fig. 14 shows the structure of the as-cast metal and Fig. 15 the structure obtained after correct heat-treatment.

In view of the large quantity of castings to be handled, very careful consideration had to be given to the type of furnace to be employed. Up to that time all furnaces used on this service were of the batch type, or enabled a very slow initial heating to be obtained. Hall[2] describes a furnace used for the heat-treatment of miscellaneous castings in manganese steel, in which the castings are allowed 45 mins. to attain a temperature of 500 deg. C. (950 deg. F.), and approximately a further 30 mins. to reach 1,000 deg. C. (1,830 deg. F.). Clark and Coutts[3] recommend 100 deg. C. per hr. as a suitable rate of heating up to 750 deg. C. (1,380 deg. F.), and soaking at this temperature to ensure uniformity before accelerating the heating up to the desired temperature.

When dealing with relative brittle castings having a very low thermal conductivity, it would appear at first sight unwise to heat them rapidly to a high temperature. The author was, however, convinced that to handle the necessary production in the space available it would be necessary to use a continuous heat-treatment furnace and to charge the castings into a fairly high temperature. It can now be admitted that it was, nevertheless, with some trepidation that the decision was finally taken to instal a gas-fired rotary hearth furnace, as shown in Fig. 16. This furnace is provided with a hearth divided into fifteen stations which can be rotated round a central axis. The castings to be heat-treated are charged in at one door and make a complete circuit of the furnace before being discharged at another door, one station removed from the charging point. With a temperature of 1,050 deg. C. (1,925 deg. F.) at the discharge, it is possible with the best adjustment of the burners, to reduce the temperature by 100 deg. C. at the charging door, giving a temperature of 950 deg. C. (1,740 deg. F.), and it is into this tempertaure that the castings are charged.

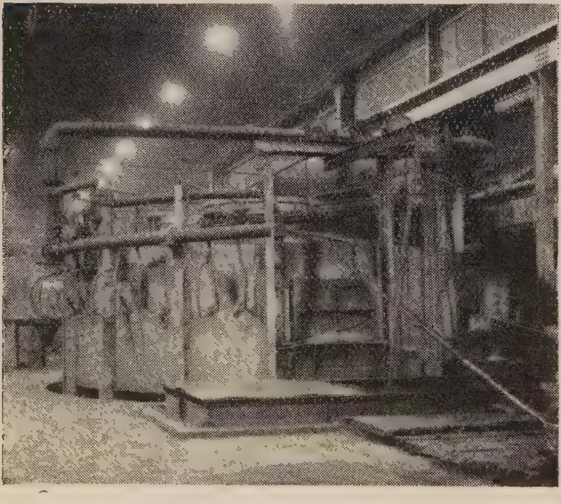

FIG. 16.—GAS-FIRED ROTARY HEARTH FURNACE USED FOR THE HEAT TREATMENT OF MANGANESE STEEL TRACK LINKS.

The operation of the furnace is extremely simple. Six castings are charged on to a station, as shown in Fig. 17. These castings are allowed to remain in this position for 11 mins. before the hearth is moved round by one station to enable a further six castings to be charged. The complete cycle to the quenching point thus takes two and a-half hours, and is made up of approximately 45 mins. in heating up to 1,050 deg. C. (1,925 deg. F.), and 105 mins. at this temperature. Operation is continuous, and each time six links are discharged and quenched a further six castings are charged. The simple apparatus installed for loading and discharging is very effective, and enables both these operations to be effected in less than 30 secs.

The method adopted for removing the links for quenching is shown in Fig. 18. The castings on entering the quenching tank fall into a steel basket, which is replaced by means of the overhead crane at regular intervals. Scale which falls to the bottom of the tank is removed periodically. The heat-treatment section is operated 168 hrs. a week, and there is no difficulty in handling the whole output of the foundry in the two furnaces provided.

Scaling

A very important consideration in the establishment of a correct heat-treatment cycle is the question of scaling. Because these castings had to be made to such close dimensional tolerances, it was impossible to decide on the final dimensions of the patterns and coreboxes until reliable information was available on the amount of metal which would be removed by scaling. Pre-

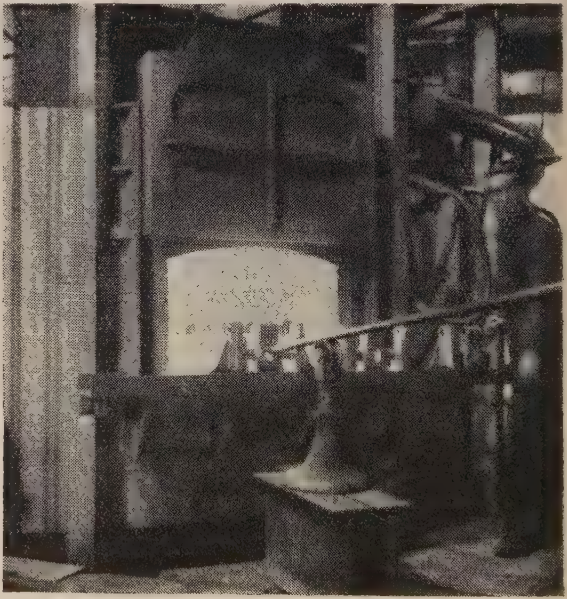

FIG. 17.—CHARGING POINT OF ROTARY FURNACE, SHOWING METHOD OF LOADING TRACK LINKS.

liminary tests were made in a small experimental batch furnace, and this enabled final adjustments to be made rapidly when the continuous furnaces were put into operation. When production started in the new furnaces, the problem was to secure the correct microstructure in the castings without excessive scaling, which would have necessitated major alterations to the patterns and coreboxes. This was successfully accomplished, and the final scaling results in a loss of approximately $\frac{1}{64}$ in. from the surface of the castings, that is, an increase of $\frac{1}{32}$ in. on internal, and a decrease of a similar amount on external dimensions.

In order to keep the pitch of the links correct, it is essential that there shall be no wide variations from the average scaling, and every care has therefore to be taken to keep constant both the temperature and atmosphere of the furnaces. Recording pyrometers enable control to be obtained over the temperature, and control over the atmosphere is obtained by manual adjustment of the burners as considered desirable after the examination of quenched castings for depths of scale. These tests are taken at frequent intervals on castings removed from the quenching tank.

An interesting point in connection with scaling is the dimensions of the cores used for the spindle holes. It will be seen from Figs. 17 and 18 that the castings are charged into the furnace so that they stand on the two-lug end. The spindle holes in the three-lug end are therefore nearer the burners, and it has been found that the scaling in these holes is more than that which takes place in the spindle holes in the two-lug end nearer the hearth of the furnace. Because of the small tolerance allowable on the finished diameter of these holes, it has been necessary to provide cores for the three-lug end spindle holes, 0.025 in. dia. smaller than those used in the two-lug end.

It is also worthy of mention that the diameter of the coreboxes used for the spindle cores in the three-lug end is exactly the same as the diameter of the finished holes. That is to say, in this particular case, the expansion of the core on drying, the contraction of the metal on cooling from the molten state, and the scaling on heat-treatment all cancel each other out and result in a hole exactly the same size as that in the corebox.

It may appear wasteful, especially under the present emergency conditions, to allow the castings to become cold before they are again heated for quenching. The author is firmly of the opinion that under normal conditions it is always advisable to carry out cleaning and fettling operations before heat-treatment, but in the interests of fuel economy this question was investigated and a trial was made in which castings were taken at a temperature of approximately 900 deg. C. (1,650 deg. F.) from the shake-out and charged into the heat-treatment furnace.

It was proved that a satisfactory microstructure could be obtained with a very short heat-treatment cycle, of the order of only 30 mins. A serious difficulty was encountered, however, in the removal of the runner from the hot casting, and it was found that at a high temperature this would bend, with the danger of seriously distorting the casting, but would not break. All fettling had, of course, to be carried out after heat-treatment and chipping away flash, etc., thus became impossible. This very considerably increased the time required for fettling. Charging the castings into the furnace and quenching them at the rate at which they were produced presented many problems, and the attempt was finally abandoned.

Final Inspection and Assembly

When the castings are removed from the fettling tank they are delivered by the overhead crane to the finishing and inspection section. Here the castings are carefully inspected for size and defects. Representative castings are jigged to check all main dimensions. The actual finishing required is very small, and consists mainly of removing scale and any slight surface inperfections from the spindle holes. Scale can be easily removed by hammering and hicycle grinders are also used, but the number of castings requiring grinding is small. The heat-treated castings are sufficiently ductile to enable spindle brackets, which have become slightly out of alignment in heat-treatment or at the shake-out, to be knocked into line with a hammer.

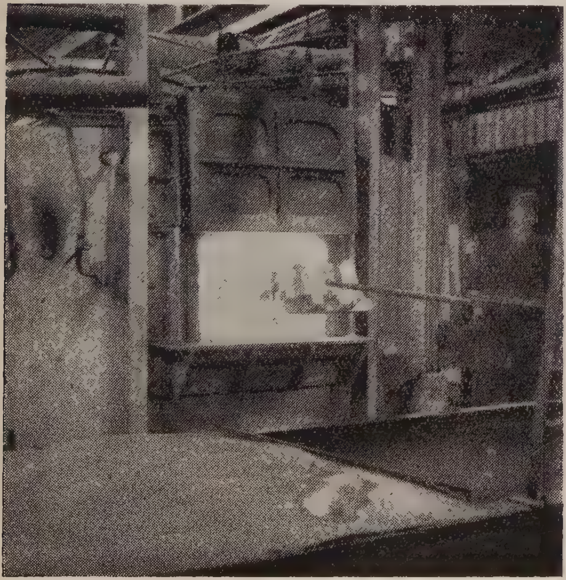

FIG. 18.—DISCHARGE POINT OF ROTARY FURNACE, SHOWING TRACK LINKS BEING UNLOADED FOR QUENCHING.

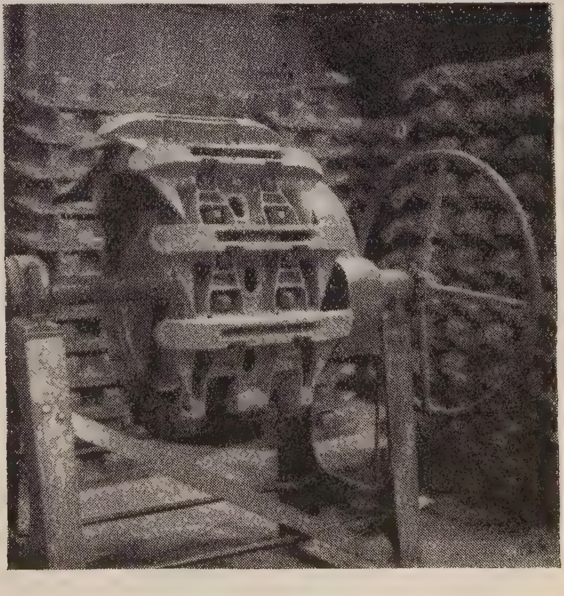

FIG. 19.—TESTING PITCH OF ASSEMBLED TRACK LINKS ON STANDARD SPROCKET WHEEL.

No welding is permissible, and castings are rejected if any slight draw or other shrinkage defect, slag hole, etc., is present in a vital part, such as the spindle brackets or roller paths. Any heavy grinding which may be necessary, for example, the removal of a part of a gate left on during fettling, is also carried out at this stage, but here again the percentage of castings requiring such treatment is not high.

The scaling which occurs on heat-treatment sometimes reveals defects which were not apparent on the rough inspection in the fettling section. Cracked castings are more readily identified owing to the action of the heat-treatment in opening up fine hair cracks, and the same applies to small draws and slag holes. The total rejects on final inspection does not, however, average more than 1 per cent., making the total of rejected castings from all sources a little under 4 per cent. of the total production.

It might be mentiond here that one important reason for keeping the scrap to an absolute minimum, which does not arise where the steel is made in the electric furnace, is that there is a limit to the amount of scrap which may be remelted. Under present production conditions, only approximately 25 per cent. of the scrap castings and sprue is remelted in the cupola charges, and the remainder has to be sold. Fortunately, there is a ready market for this scrap among ironfoundries, some of which find such material useful for increasing the manganese content of cupola mixtures.

When finished, the castings are assembled with their spindles into batches of six links, and each batch is checked for correct pitch by being passed over a standard sprocket wheel, as shown in Fig. 19. This is known as the wrap test and is the most important of the dimensional tests. The sprocket of the first link is fitted tightly against a tooth on the test wheel and this link thus becomes the driving link. The wheel is then turned until all the link sprockets are engaged. Each casting must seat well down on the wheel and then the clearance between the sprocket of the last link and the corresponding tooth is measured. For the sub-assembly to be passed, this clearance must be not less than 0.25 in. and not more than 0.35 in. The retainers for the spindles are then fitted and the sub-assembly is ready for despatch.

Metallurgical Control

When producing heats of manganese steel continuously by the process used in this plant there is, of course, a possibility that, due to a combination of adverse conditions, a heat of steel may be made with a composition outside the specified limits. This does happen on very rare occasions, though the plant has sometimes run for weeks without a heat of wrong analysis. It is, however, necessary when the need arises to find every casting poured in any particular heat. In order that this shall be possible, each casting is numbered.

A pattern number is fixed permanently to each pattern, a date number is also fixed to the pattern, but changed each day and finally every mould made from each pattern is numbered consecutively, the number being imprinted on the mould face. At the same time, the pattern and casting number is chalked on the side of the box, as can be seen on referring to Fig. 6. As each heat is poured, a girl records the numbers of the castings and thus at the end of the shift a complete record is available, giving not only the number of each casting in every heat, but also the relative position of each casting during pouring. Should a heat prove of wrong analysis, the castings can be found and rejected during the rough inspection in the fettling section.

During the early stages, when the plant was being put into operation, this casting record was found of the greatest value in assessing the cause of the various types of defects encountered. A copy of the record was sent to the fettling section and the condition of each casting examined was briefly entered against its number. The record then went to the final inspection, where further details were recorded. In this way it was possible to examine the influence of both pouring temperature and composition on the various defects encountered.

One point revealed by this system, for example, was that certain castings which had the appearance of having been poured with cold metal and which contained cold laps, were actually poured first in the heat with the hottest metal and the defects were due to discontinuities in pouring from a full ladle.

Cracks in Manganese Steel Castings

One of the most serious metallurgical problems encountered was in preventing the occurrence of cracks in the castings. It must be remembered that, when these cracks were first met, many of the conditions in this plant—for example, at the shake-out, in the fettling section and in heat-treatment—differed widely from anything previously attempted in the manufacture of castings in manganese steel. A disconcerting feature of the trouble which suggested that none of these conditions could be entirely responsible, was that all the castings did not crack, one being found badly cracked and perhaps the next casting in the same heat, which had apparently received identical treatment, would be quite sound.

Cracks in various forms persisted for some time before being brought under control, and a very complete series of investigations was carried out to determine their causes, including examination of the influence of pouring temperature, the temperature of the casting at the shake-out, and its rate of cooling, the treatment in the fettling section, the rate of heating and the position of the casting in the heat-treatment furnace, as well as the effect of composition and mould conditions, etc. The cracks were found to be of two main types, large cracks present in the castings prior to heat-treatment, which will be referred to as hot tears, and smaller cracks, usually only discernible after heat-treatment, which will be called hair cracks.

Hot Tears

This type of crack could usually be detected on rough inspection before heat-treatment and occurred generally on one or more sides of the square recesses in the link between the spindle brackets and the road face. These square recesses can be seen on referring to Fig. 1. The blue coloration of the fractured surface showed that these cracks were formed during the cooling of the castings from the molten state and that the castings were at a fairly high temperature when the crack developed. When very small, these cracks might not be identified in the fettling section and were then found at the final inspection after the heat-treatment had opened and spread them.

Experience showed that four main factors were responsible for this type of defect, and they are arranged in what is considered to be their correct order of importance, as follows:—

(1) *High Carbon.*—Too high a carbon content in the steel, especially if the carbon is high in relation to the manganese content, will increase the tendency to the production of hot tears. A casting containing a carbon content of 1.4 per cent. is more likely to tear than one containing 1.2 per cent. carbon and a casting containing 1.2 per cent. carbon with 13 per cent. manganese is less likely to crack than one containing 1.2 per cent. carbon with 11 per cent. manganese. The effect produced by the converter slag when allowed to come into contact with the molten

ferro-manganese and its influence in yielding a high carbon content with a relatively low manganese was discussed earlier in the Paper. Another factor which will produce similar results is the stopping of the converter blow before the whole of the carbon has been eliminated from the steel. The aim should be to produce converter steel containing not more than 0.10 per cent. carbon.

(2) *High Phosphorus.*—Published information[3 4] suggests that phosphorus up to 0.125 per cent. has no deleterious influence on manganese steel castings. Positive evidence has, however, been obtained that this element greatly increases the tendency for the production of hot tears in mass-produced castings in this metal. In one test, all other conditions were kept constant and five heats were made with a phosphorus content of 0.08 to 0.09 per cent. A further five heats were then cast with the phosphorus increased to 0.12 to 0.13 per cent. More than 200 castings were poured in each range. Of the high phosphorus castings, no less than 61 per cent. were rejected because of hot tears, while the rejects in the low phosphorus range totalled only 3.5 per cent.

In the acid lined converter, such as is used in this plant, there is, of course, no possibility of removing phosphorus when the steel is made, as may be done in the basic electric process. All phosphorus present in the cupola metal and in the ferro-manganese therefore goes into the steel. The ferro-manganese normally contains 0.20 per cent. phosphorus, which means that when the manganese addition is made to the converter metal, the phosphorus content is increased by about 0.04 per cent. If all other conditions are satisfactory, little trouble may be expected from hot tears if the phosphorus content of the finished steel does not exceed 0.10 per cent. The phosphorus in the cupola metal must, therefore, be kept below 0.06 per cent. and preferably below 0.05 per cent. This can only be done by using the best quality steel scrap and pig-iron in the cupola charges.

(3) *Incorrect Mould Conditions.*—Too strong a mould, that is, the use of moulds rammed too hard or made with sand of very high dry strength, has been shown to increase the tendency to produce hot tears. It was found that excessive moisture, especially if used in conjunction with high bond, would produce these defects. This high moisture and bond are revealed by the use of the plasticity of shatter test already described, and it is necessary that the properties of the sand shall be kept within the specified limits and that excessive mould hardness is avoided.

(4) *High Pouring Temperature.*—Investigation showed that the first castings poured from any heat were more prone to show hot tears than castings poured later, when the metal was cooler. A high pouring temperature, say in excess of 1,500 deg. C. (2,730 deg. F.), produces long columnar crystals in the castings, and these are apparently a source of weakness during cooling. Cracking was found frequently to occur in this type of crystal formation.

One slightly incorrect condition may not be sufficient to cause serious trouble from hot tears, but experience has shown that a combination of more than one of the above factors, which individually would not be considered serious, can cause a considerable loss of production from this source.

Hair Cracks

Two types of hair crack were experienced:—(1) Cracks produced during quenching, and (2) cracks produced by rough handling of the castings in the as-cast condition.

Quenching Cracks.—These cracks are only produced when the free carbide in the castings has not been wholly taken into solution before quenching. As would be expected, this trouble was met in castings in which the carbon content was high, especially if the ratio of manganese to carbon was less than 10:1. It has been proved that with a sufficiently long soak at a suitable temperature, quenching cracks can be avoided, even if the carbon is higher than normal, but under production conditions it is not possible to vary the heat-treatment to suit the composition of the metal, and this is another reason why it is important that the metal composition should be kept within the specified limits.

Cracks Produced by Rough Handling.—In most cases it was established that cracks found after quenching were made more easily detected by the heat-treatment cycle. If the structure of a casting, containing hair cracks, is examined and no free carbide is found, this is taken as proof that the cracks were produced before quenching. Rough handling of the castings in the as-cast state, such as throwing them down, excessive hammering, rumbling, etc., will produce minute cracks which are opened out and increased in size by heat-treatment. Cracks are likely to be produced when short pieces of flash, whistlers or gates are knocked off and by heavy grinding, before heat-treatment, to remove such pieces. Very rapid heating of the casting from the cold is also avoided, as this not only produces cracks by thermal shock, but also increases the tendency for any minute cracks already present to spread. It has been found necessary, in this connection, to allow at least 15 min. for the castings to reach a temperature of 500 deg. C. (930 deg. F.) from the cold.

Testing the Metal

Routine tests carried out on the metal include chemical analysis, which is made on every heat, hardness tests and metallographical examination. For analysis a special test sample is cast when approximately half the metal from a ladle has been poured. This is taken while still red hot and placed in a muffle at a temperature of 900 deg. C. (1,650 deg. F.) for 30 min. and afterwards removed and allowed to cool in air. The sample can then be drilled using a heavy drilling machine, and a ½ in. dia., high-speed steel twist drill running at about 150 r.p.m. Samples not heat-treated in this way cannot be drilled successfully. Before the heavy drilling machine was used, an attempt was made to secure a pellet sample for analysis by pouring the liquid steel from a height of about 15 ft. into water. This method of sampling was, however, found to be unreliable, the silicon content of the metal especially differing from that obtained on drillings.

Micro-examination is usually carried out on samples taken from actual links after heat-treatment. The sample is cut from the casting, using an elastic emery wheel, and this operation must be carried out slowly, at the same time keeping the sample cool, as otherwise the structure of the metal is likely to be modified. Numerous micro-examinations were necessary in arriving at the most suitable heat-treatment cycle. Now this has been established, only an occasional examination is made as a check on operating conditions.

Tensile tests have occasionally been taken on the steel and the results obtained compare very favourably with those from manganese steel produced in the basic electric furnace. The following are typical figures:—Maximum stress, 65 tons per sq. in.; reduction of area, 42 per cent.; elongation on 2 in., 64 per cent.

Samples from each heat of steel after heat-treatment are tested for Brinell hardness and the test is carried out using a 3,000-kg. load and 10-mm. ball. Care has to be taken in preparing the surface of the sample for the test, as due to decarburisation, which occurs to a slight extent during heat-treatment, the skin of the casting becomes hard and, unless this is removed, a high reading may be obtained. On the other hand, manganese steel hardens rapidly by cold work and a hard skin may be produced in preparing the surface for the test. For these reasons the use of any hardness measuring test which produces a relatively small impression will be likely to yield incorrect results. The hardened layer is, however, only superficial and using the Brinell test with the heavy load and large ball, its effect is almost negligible. Correctly heat-treated manganese steel usually has a Brinell hardness number between 180 and 200.

Acknowledgements.—Under present conditions, the author is unable to mention by name those firms and gentlemen to whom acknowledgment should be made for the part they played in the work described in this Paper, but this omission will be rectified at the earliest opportunity. In the meantime, the author wishes to express his thanks to members of his staff who have assisted him in the preparation of this Paper.

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Birmingham, Coventry and West Midlands Branch **Paper No. 783**

Electric Furnaces in the Manufacture of High-Duty Cast Iron

By T. R. TWIGGER* (Member)

The object of this Paper is to record some personal views and experiences covering the application of electric furnaces in the manufacture of high-grade cast iron, and to indicate the principal factors governing the selection and operation of such furnaces. It should be made clear that the operating conditions in the author's works are different from those obtaining in many foundries, as the system of furnace operation has been arranged to give not only economical operation of the furnace itself but economical operation of the unit of which it forms a part.

Previous Institute Papers

Although Papers on the use of electric furnaces for cast iron were read in this country and America in 1919, that given by G. K. Elliott to the Institute's Annual Conference in 1921 is the author's recollection of the earliest Paper on the subject, and it well merits reading or re-reading by those interested. Progress has been such that there must now be few instead of many who "look upon the occasional adoption of the electric furnace for such common material as cast iron as either foolish extravagance or metallurgical affectation." Elliott's work referred chiefly to a basic-lined furnace on account of its cleansing, degasifying, and sulphur reducing possibilities. A Paper on "Electric Furnaces in the Foundry" was given to this Branch of the Institute by D. Wilkinson in 1921. This Paper, like that of Elliott, emphasised the advantages of duplexing, thus retaining the low melting cost of the cupola, but Wilkinson considered the basic furnace useless when used intermittently—possibly owing to the unsatisfactory basic lining materials then available. Curiously enough Wilkinson's Paper gives a hypothetical scheme for cupola/electric duplexing, very similar to that in operation in the author's works. A very comprehensive and recent review of electric furnaces operating on cast iron is given in Robiette's book: "Electric Melting Practice."

There can be no doubt that the development of cast iron in the direction of greatly increased strength—usually the result of reduced carbon content, or the addition of alloys, together with the necessity in many cases for high pouring temperatures—greatly widens the scope for electric furnace applications, although, except perhaps in one or two isolated cases, the cupola continues, and is likely to continue, to provide the bulk tonnage of normal grades of cast iron.

Factors Influencing Electric Furnace Application

Compared with normal cupola melting, the electric furnace will:—

(1) Produce to very close limits of composition with very low losses—a point of importance with expensive alloys.

(2) Produce low carbon and alloy irons of high strength which it would be difficult, if not impossible, to produce in the cupola.

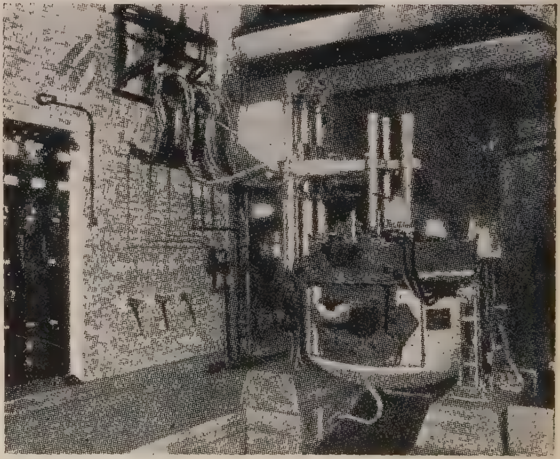

FIG. 1.—'LECTROMELT FURNACE AS USED FOR MAKING HIGH-DUTY CAST IRON.

(3) Utilise scrap material of low market value such as turnings and borings, even though the excessive bulk of these materials compared with normal solid charges, limits the amount the furnace will hold.

(4) Superheat to very high temperatures should this be desired.

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(5) Act as a receiver, maintaining molten metal temperature without serious change in composition unless held for an excessively long period.

(6) Under suitable conditions desulphurise, where this is necessary.

The electric furnace will not:—

(1) Melt normal grades of pig-iron and scrap at a cost comparable with that of cupola melting.

(2) Provide a continuous supply of molten metal over a normal working day unless operated on the basis of first melting a cold charge and then adding cold metal and withdrawing molten metal at regular intervals; obviously the throughput in such a case would be somewhat limited.

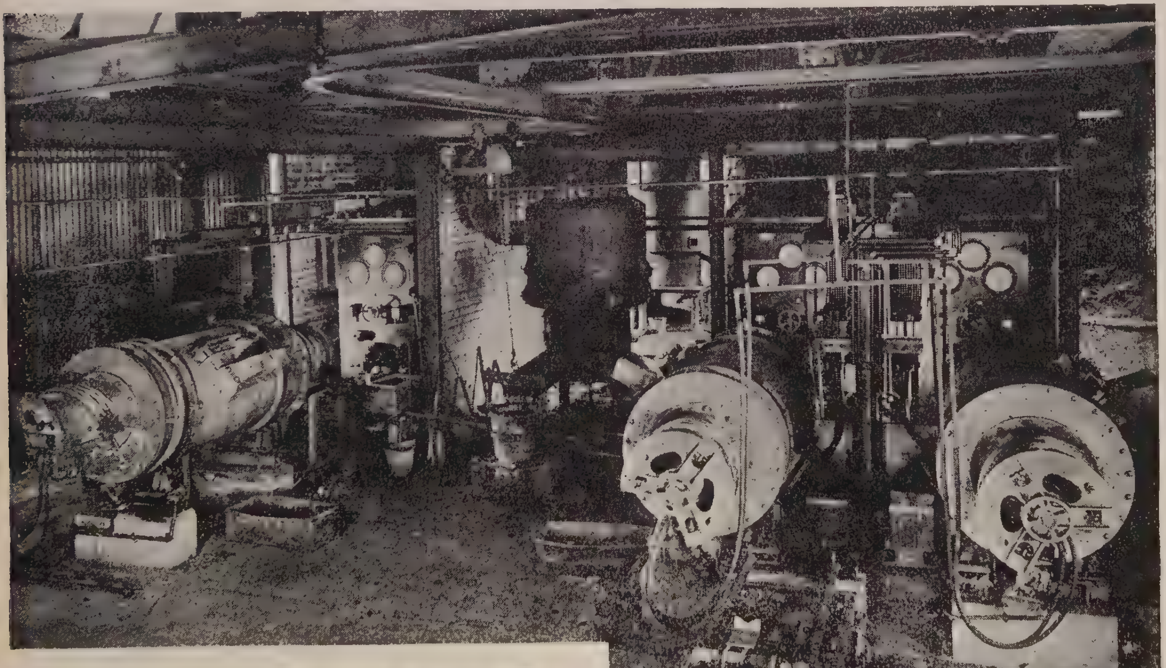
A point worth noting is that unless precautions are taken, electric furnace metal, possibly on account of the high temperature conditions prevailing, especially in the vicinity of the arc, may tend in small sections to solidify in the supercooled condition, giving a structure which for some purposes may be undesirable. A further point is that maximum economy of operation is only obtained by working 24 hrs. per day.

Types of Furnace Available

Direct Arc, usually 3-phase, with top electrodes and automatic electrode control except on the very small sizes. The larger furnaces may be arranged for top charging. Tilting may be either by hand on the smaller sizes, by motor, or by hydraulic pressure, and pouring can be effected either by tilting on a central axis or by lip pouring at a constant level. Such furnaces are eminently suited to the usual 3-phase supply. A typical furnace, shown in Fig. 1, with which the author is familiar is a 'Lectromelt "S" type having a nominal capacity 1,500 lbs. cold charge.

Indirect Arc.—A typical furnace (shown in Fig. 3) is the Detroit or Birlec-Detroit rocking arc. In such furnaces heating is effected by radiation from the arc and by conduction from the furnace wall. The temperature required for even low carbon cast iron is usually not sufficiently high to cause serious loss of life on the lining, which is a factor to be reckoned with when considering the use of small furnaces of this type for steel and other high melting point alloys. The Detroit type is a single phase furnace, and difficulty is sometimes experienced with supply authorities, unless the load can be balanced, as for example by using three furnaces. Personal experience of furnaces for 350 lbs. cold charge or 500 lbs. molten, operating on low alloy irons, and also on austentic iron of the Ni-resist type, has been very satisfactory.

Induction Furnaces.—These are very efficient melt-



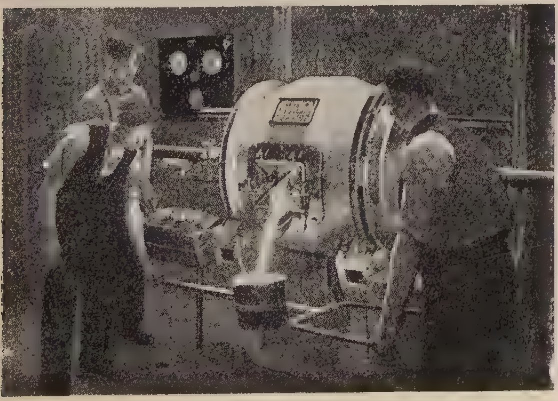


FIG. 2 (ABOVE).—RESISTANCE-TYPE ELECTRIC FURNACES USED IN CONJUNCTION WITH THE CUPOLA FOR THE DUPLEX PROCESS.

FIG. 3 (LEFT).—THE BIRLEC-DETROIT FURNACE INSTALLED FOR THE MELTING OR DUPLEXING OF CAST IRON.

ing furnaces, but of very high capital cost. They are finding increasing application for high-grade steels, but although economic in operation due to the absence of electrodes, low refractory costs, etc., their technical advantages are not generally of such attraction on cast-iron alloys as to overcome the objection to the very high capital cost.

Resistance Furnaces.—Considerable use is made of furnaces having a central carbon resistor. The writer has no personal experience of this type of furnace, but has been informed that the furnace, shown in Fig. 2, is considered quite satisfactory on cast-iron alloys, including the Ni-resist type of material.

In the works with which the author is connected electric furnaces have been utilised chiefly for modifying and alloying cupola metal for special purposes, in connection with a centrifugal casting foundry which must of necessity operate on a continuous basis, involving a continuous supply of molten metal over a 9-hr. shift. Although careful attention is given to maximum economy of furnace operation, the overall efficiency of the complete production unit is of prime importance. For example, it would be preferable to have the electric furnace metal ready a short time before required, and use current to keep the metal hot rather than have a number of casting machines and operators waiting for metal.

Two principal methods are in use:—

(1) Production of molten metal, either from a cold charge, or more often modifying cupola metal of such a composition that the desired final composition can be achieved by using a percentage of the special electric furnace metal with the balance of cupola metal. This is the method usually practised with the rocking arc furnace. Since the supply must be continuous, two electric furnaces must be used, or alternatively when using one electric furnace the metal may be stored in a crucible furnace. This method is regularly used for austenitic cast iron of the Ni-resist type, the final mixture consisting of 50 per cent. cupola metal with 50 per cent. electric furnace metal. Table I represents a typical charge.

The advantages of this particular scheme can be detailed as under: (*a*) It is possible to obtain a large output of any special composition that may be desired from a relatively small amount of special alloy iron, and (*b*) the cupola may be kept continuously melting one standard mixture, thus avoiding special charges which it is difficult—and in some cases impossible to keep separated. When using this method it is, of course, necessary to exercise very close control over the relative weight of the two different mixtures, although under some conditions measurement in a ladle can be relied upon. In view of the ever-increasing tendency for continuous plant operation, it is thought that this method offers considerable scope for accommodating castings which require special provision as regards composition.

(2) Continuous Duplexing of Molten Cupola Metal. —In this case molten metal, as near as possible to the desired final composition, is melted in a cupola, and transferred at 10-min. intervals to a 'Lectromelt furnace in which a 7-cwt. cold charge has already been melted. Alloy or steel additions as necessary are made, and the metal withdrawn usually at 10-min. intervals for casting. With the system of continuous duplexing already described the handling of the molten metal into and from the furnace needs careful con-

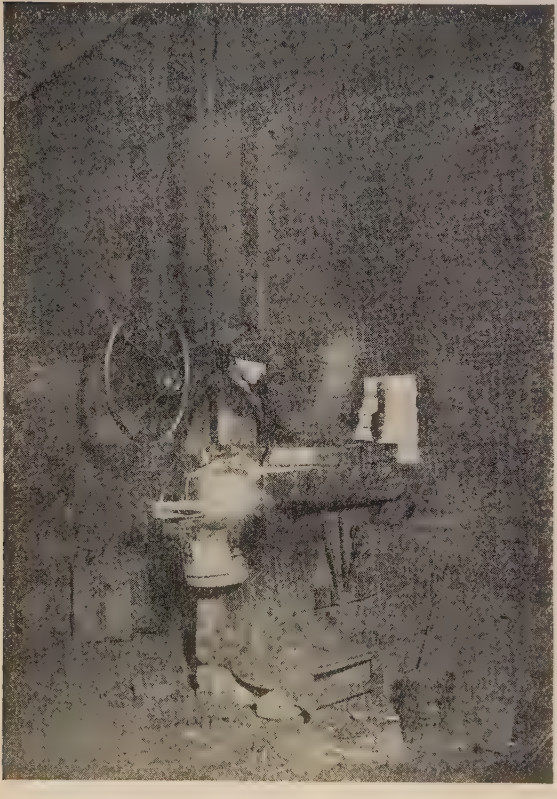


FIG. 4.—TAPPING THE CUPOLA-MELTED METAL INTO MONORAIL-SUSPENDED LADLES.

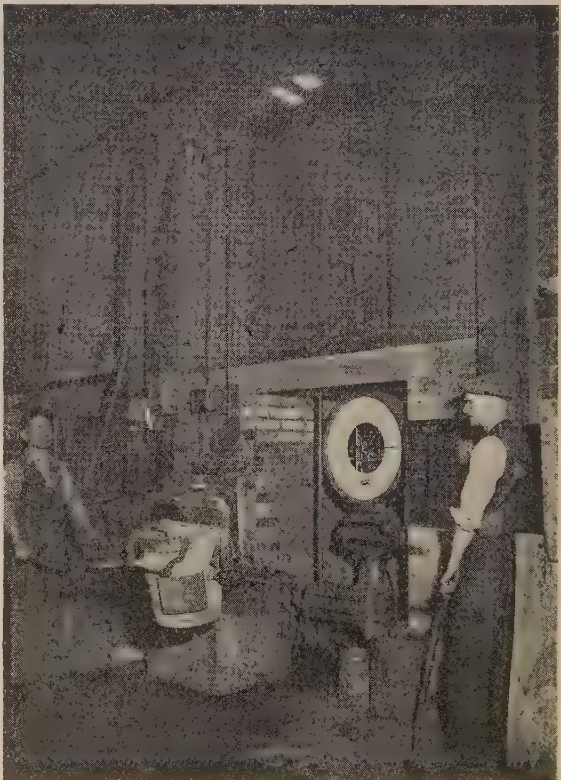


FIG. 5.—WEIGHING THE METAL EN ROUTE TO THE ELECTRIC FURNACE.

TABLE I.—*Electric Furnace Charge Sheet.* October 12, 1942.

Cast No. Z.8. *Centrifugal Foundry. Furnace No. 3 (Rocking Arc).*

Mix. No.	Charge.	Alloys, etc.	Time start.	Time charged.	Time tapped.	No. of charges.
8 Alloy	148 lbs. alloys .. 22 ,, steel .. 130 ,, cup. No. 8 (molten) — 300	Nickel .. 86 lbs. Fe-Chrome .. 21 ,, ,, Phos. .. 5 ,, Copper .. 36 ,,	1st charge, 7.0	7.30	8.30	—
			Meter	Meter	Meter	4½
			897,100	897,150	(1st charge) 897,370 (last charge)	

Above used with equal weight of Cupola Mixture No. 8.

		T.C	Si	P	Mn	Ni	Cr	Mo	Cu
8 alloy mixed 50 per cent. with No. 8 cup.	Com. cal.	1.82	1.75	0.77	0.50	27.8	4.93	—	12.0
	Assumed loss	0.02	0.06	—	0.05	—	0.10	—	0.10
	Com. expected	2.57	1.92	0.84	0.60	14.0	2.49	—	6.0
	Com. actual	2.61	1.90	0.84	0.62	14.12	2.40	—	6.17

Average current consumption 450 units per ton.

sideration. Cupola metal is tapped into a 2½-cwt. ladle (see Fig. 4), which is transported by monorail to the 'Lectromelt furnace, passing en route over a section of the monorail connected to a weighing machine (Fig. 5). The weight over or under the nominal 2½ cwts. is recorded on a board, which is inspected by the control metallurgist at frequent intervals. In this way correction can be made if necessary to the weight of steel, alloys, etc., being added to the furnace. Actually in practice the need for adjustment is very small. The metal is added to the electric furnace through what is normally the tapping spout (Fig. 6), and is withdrawn by pouring into a runway ladle (Fig. 7) for transportation to the casting machine, direct pouring into the runner basin being effected from the conveyor ladle (Fig. 8); in this way no metal is carried by hand.

TABLE II.—*Synchronisation Scheme between Electric Furnace and Cupola.*

ELECTRIC FURNACE.	a.m.	CUPOLA.	a.m.
Melting commences ..	7.0	Blow commences ..	7.45
		Metal tapped ..	8.5
First metal added from cupola	8.15	First tap into 'Lectromelt	8.15
First metal tapped ..	8.30	Cupola off	12.15
Last metal tapped at	12.40	Last metal withdrawn	12.30
Leaving approx. 7 cwts. in furnace.		Blowing recommences	1.15
First metal added ..	1.30	Metal poured into 'Lectromelt ..	1.30
First metal withdrawn	1.45		
Last metal added ..	5.0	Cupola shut down ..	4.45
Last metal withdrawn	5.45	Last metal withdrawn	5.0

Details of the first cold charge are given in Table III and for the duplexed material in Table IV.

Obviously the amount of cold material which can be added is controlled by the amount and frequency of metal withdrawn. This method has the advantage that the bulk of metal is melted cheaply in the cupola, and a large throughput is obtained from one electric furnace. Synchronisation between electric furnace and cupola is arranged, and is illustrated in the timetable, Table II.

Apart from the first heat of the day already referred to, cold melting is practised in some cases—notably on a special iron of great heat and corrosion resistance, having approximately 1.7 per cent. carbon and 30 per cent. chromium. Such material made under the trade name "Bricrome" can be melted in a rocking arc furnace, but on account of the high casting temperature required the 'Lectromelt furnace is preferred.

This very low carbon iron is one which it would be difficult, if not impossible, to produce from a cupola.

Linings

High-duty cast irons usually necessitate high pouring temperatures, but steel melting temperatures are usually not necessary, therefore wear and tear on the linings is usually less severe than in steel furnaces; nevertheless, lining costs represent an appreciable item in operating costs and must be controlled—not only must the actual cost of lining itself be studied, but also the loss of output and inconvenience in production due to a furnace being out of action if frequent relining is necessary.

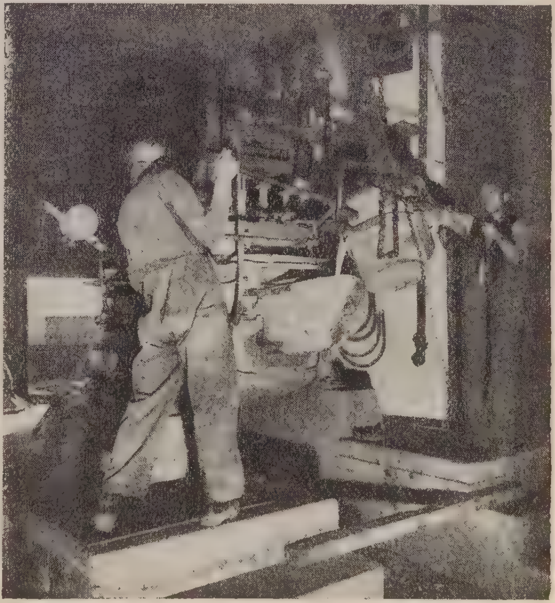


FIG. 6.—TEEMING THE METAL INTO THE ELECTRIC FURNACE.

(*a*) *Rocking Arc* (350 *lbs. cold charge capacity*).—Most of the materials dealt with have not necessitated a basic lining, therefore experience has been confined to sillimanite bricks, and rammed ganister of good quality. The latter is considered by far the better proposition. Since the furnaces are sometimes operated on cold melting (using either a complete cold charge, or first melting the solid part of the charge then adding molten metal), or sometimes entirely on duplexing molten metal with relatively small amounts of solid material, it is not possible to give precise details of lining life in terms of number of heats, but it can be stated that with a small amount of daily patching round the door and internal patching weekly, and using charges consisting of 50 per cent. solid material and 50 per cent. molten metal, a life of 1,000 heats is expected. The design of this type of furnace lends itself to the use of interchangeable shells which greatly minimises shut-down time when relining is necessary.

(*b*) *'Lectromelt* (*15 cwts. nominal cold charge capacity*).—This furnace has been operated on the basis of one cold charge, with subsequent molten metal additions and withdrawal as previously described, and with a basic lining, which was considered desirable in view of the furnace occasionally being used for the high chromium alloy previously referred to. Experience with the particular monolithic lining so far tried indicates that with a certain amount of daily patching, the life is 30 working days before it is necessary to reline the side walls, the amount of metal dealt with during this period being approximately 10½ tons melted cold and 160 tons duplexed. With a monolithic lining side wall repair consists of removing the roof ring, inserting a steel former and ramming the lining material, usually bonded with wire nails. No lengthy dry-out period is necessary, and the furnace can be put into immediate use. The roof ring, which is water-cooled near the steel casing, is constructed of sillimanite bricks set in sillimanite cement, and a life of approximately 50 working days is obtained.

Charging, Melting and Slagging

(*a*) *Rocking Arc.*—When charging the rocking arc furnace, heavy material such as pig-iron is placed on the bottom and smaller material on top; if charging very light material the charge may surround the electrode, and this is not detrimental. The later editions of these furnaces are equipped with automatic rocking gear mechanism by which the initial angle of rock and rate of subsequent increase follow a predetermined setting.

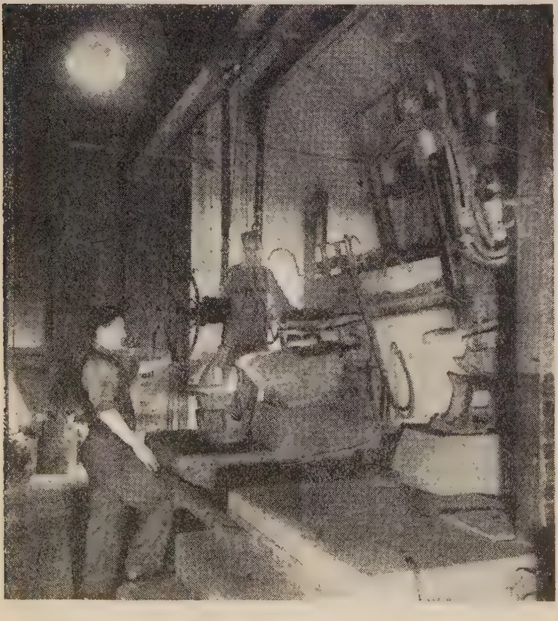


FIG. 7.—TAPPING THE ELECTRIC FURNACE WHICH IS FITTED WITH A SLAG-TRAP SPOUT AS SHOWN IN FIG. 9 (SEE DISCUSSION).

On normal types of cast iron no slag-forming materials are added. A certain amount of slag is formed, this is usually thick and no trouble is experienced when tapping metal through the small door aperture. At the end of a heat—or more usually at the end of a day, the slag is emptied by removing the door, rotating the furnace so that the door is at the lowest position, and striking the arc for a few minutes.

(*b*) *'Lectromelt.*—When melting cold charges, any heavy material is placed on the hearth, and the top layer always consists of fine scrap. Under these conditions direct shorting is avoided, which would be the case if large lumps were near the electrodes before the bath is formed. Four voltage tappings are provided, melting commencing on No. 1 with No. 2 used when the bath is formed. Nos. 3 and 4 are used for maintaining temperature when molten. In view of the basic lining it is necessary to provide a basic slag and reducing conditions in order to avoid attack on the lining by oxidised silicon. When commencing with a cold charge, 12 lbs. crushed lime and 7 lbs. crushed anthracite are added, subsequently some slag is removed every two hours and the slag renewed by the addition of 10 lbs. lime. Before the mid-day break a further 7 lbs. of anthracite are added. The melting time is normally 1½ hrs. (first heat) and after the pouring temperature has been reached the metal may stand 30 min. without appreciable loss of temperature. The slag formed by the additions mentioned is capable of effecting some desulphurisation as is shown by the following figures, although desulphurisation is not deliberately sought.

Sulphur Content.

Cupola metal, 9 a.m.,	0.112 per cent.
Electric furnace metal, 10 a.m.,	0.058 per cent.
Cupola metal, 3 p.m.,	0.083 per cent.
Electric furnace metal, 4 p.m.,	0.059 per cent.

Under the system of continuous duplexing some provision is necessary to avoid the slag entering the

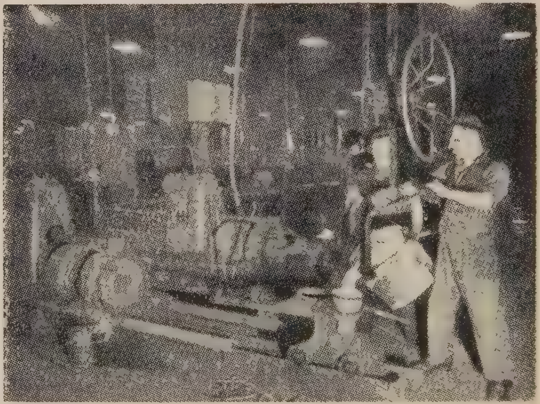


FIG. 8.—FEEDING THE SPINNING MACHINES.

TABLE III.—*Electric Furnace Charge Sheet (Solid Charge).* October 28, 1942

Cast No. Z.24. *Centrifugal Foundry. Furnace No. 4. ('Lectromelt.)*

Mix. No.	Charge.	Alloys, etc.	Time start.	Time charged.	Time tapped.	No. of charges.
Alloy 20	3½ cwt. 233 scrap .. 2½ ,, No. 1 scrap .. 1 ,, B.M.C. scrap .. — 7	Fe-Si .. .. 3 lbs. ,, Mn .. 1 ,, ,, Chrome .. 6 ,,	6.50	6.50	8.10	—
			Meter	Meter	Meter	1
			136,370	—	136,610	—

12 lbs. lime, 7 lbs. anthracite.

	T.C	Si	P	Mn	Ni	Cr	Mo
Com. cal.	3.23	2.65	0.33	0.81	—	1.09	0.85
Assumed loss	0.23	0.19	—	0.04	—	0.06	0.02
Com. expect.	3.00	2.46	0.33	0.77	—	1.03	0.83
Com. actual	2.98	2.50	0.34	0.76	—	1.01	0.82
Actual loss	0.25	0.15	—	0.05	—	0.08	0.03

Current consumption 700 units per ton.

ladle when withdrawing the molten metal. This is achieved by fixing the slag brick, shown in Fig. 9, in the pouring spout as shown in the illustration. This slag baffle is not a complete slag trap, but in practice the amount of slag poured before the level of metal is above the bottom of the slag baffle is exceedingly small. A complete slag seal would necessitate a pool of molten metal in the slag spout and this is considered undesirable.

Operating Costs

Claims are sometimes made that electric furnace cast iron can be produced at a cost equal or less than that of cupola metal. This may be true under particular conditions, but only where very cheap raw materials are available for the electric furnace. Costing systems, in particular the allocation of overheads, vary so much between different plants that no attempt is here made to give actual metal costs. In the author's opinion it is desirable always to incorporate the cost of melting in the " cost at spout " even if this involves a special allocation of overheads to cover the depreciation, etc., of the particular furnace. Sufficient has been said about lining life to furnish a basis of comparison by anyone interested. Other details bearing on operating costs may be of interest.

Electrodes and Current Consumption

Since mixed cold melting and duplexing is the rule no figures per ton melted can be given. Information on this subject is given in the section on arc furnace melting in Robiette's book already mentioned.

Sufficient data of current consumption are available to justify the following figures:

Rocking Arc:
Cold melting, 1st heat, 850 units per ton.
Subsequent heat, 750 units per ton.

'Lectromelt:
Cold melting, 1st heat, 710 units per ton.
Duplexing, 200 units per ton.

These figures are considered satisfactory in view of the operating conditions. Lower current consumptions could no doubt be obtained on larger furnaces. On the other hand, consumptions would be higher on lower carbon materials. Current is available for the electric furnaces referred to at 0.5d. per unit.

Labour

(*a*) On the 350-lb. rocking arc furnace one operator weighs out metal charges, maintains current load by hand operation of electrodes, controls pouring, and attends to lining repair.

(*b*) On the 'Lectromelt furnace, one operator with some assistance in preparing the charge, controls furnace operations and assists the operator who handles

TABLE IV.—*Electric Furnace Charge Sheet (Liquid Charges).* October 28, 1942

Cast No. Z.24. *Centrifugal Foundry. Furnace Sheet No. 4. ('Lectromelt.)*

Mix No.	Charge.	Alloys, etc.	Time start.	Time charged.	Time tapped.	No. of charges.
Alloy 20	Add to 1st charge melted 2½ cwts. cupola mix. + 20 lbs. steel	Chromex .. 1¼ lbs. Fe-Mo .. ¼ lb.	— —	— —	— —	— —
			Meter	Meter	Meter	42
			136:610	—	137,640	—

7 lbs. anthracite added during mid-day break. Slag renewed with 10 lbs. lime after each slagging.

	T.C	Si	P	Mn	Ni	Cr	Mo
Com. expect.	2.95	2.40	0.32	0.80	—	1.05	0.85
Com. actual	2.96	2.32	0.32	0.82	—	1.04	0.85
Actual loss	—	0.08	—	—	—	0.01	—

Current consumption 184 units per ton.

metal along the runway from the cupola, in pouring metal into the furnace, and also assists the operator who handles metal withdrawn from the furnace for transmission via the runway to the casting machines.

Cooling Water

(*a*) *Rocking Arc.*—In view of the small amount required to cool the electrode holders, a closed circuit, involving a circulating pump and overhead tank, serves two furnaces, thus only the cost of pump operation is involved.

(*b*) *'Lectromelt.*—This requires a fairly large volume of water, since the roof ring, electrodes, glands, and furnace doors must be cooled. With a closed circuit a water cooler would be necessary. In the author's works adversity arising through a spring which filled a concrete underground shelter, and which kept it full, despite all attempts to keep it empty, was turned to good account as a supply of cooling water, a circulating pump being the only operating cost.

Depreciation

This important item, which is high for any type of electric furnace, should be allocated to melting costs. When duplexing, the large throughput results in a low cost per ton, but for straight melting the depreciation per ton is necessarily high.

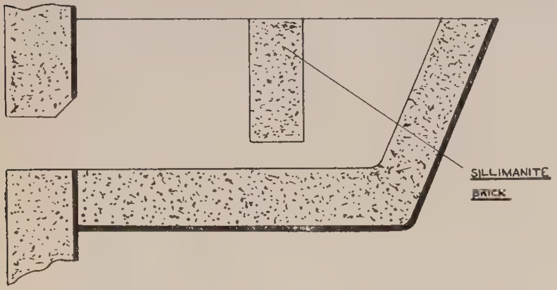


FIG. 9.—POURING SPOUT AND SLAG BAFFLE FOR THE 'LECTROMELT FURNACE.

Electric Furnace as a Receiver

To ensure a continuous supply of molten metal for special requirements, three crucible furnaces have been operated, lately on creosote-pitch oil. Such figures as are available indicate that the cost of storing in an electric furnace is lower than for crucible operation—allowing for the much higher depreciation charges on the electric furnace. In addition, the elimination of breakdowns due to crucible failure is an important point.

Conclusion

" Before closing we must sound the warning that the electric furnace is not a cure-all for the many ailments to which the iron foundry is heir. Its adoption is not a surcease from all care, for if not attended by experienced and intelligent metallurgical supervision, it can readily become the source of the greatest worry and disappointment. Efficient and versatile as the electric furnace may be, it is comparable to a highly developed machine that can be placed with assurance only in the hands of trained and intelligent operators. It needs the help of sound metallurgical sense, and well directed thought and study." These words which form the closing paragraph of Elliott's Paper 20 years ago can well end the present Paper, which it is hoped may prove of interest and help, and result in exchange of experiences which the author would appreciate.

Finally, thanks are due to the author's colleagues for ready assistance, and to the directors of the British Piston Ring Company, Limited, for permission to give this Paper.

DISCUSSION

High Temperature Not Sought

Opening the discussion, MR. E. HUNTER said there had been no mention of metal temperatures. He would like to know what degree of superheat Mr. Twigger obtained. The question of maintenance costs was also of interest. If the meeting could have an indication of how electric furnace maintenance costs compared with those in cupola working he thought it would be of value. The lecturer had stated that light material was placed on top of the charge. Did he mean turnings or borings, and if such material was not available what would he use?

MR. TWIGGER, in reply, stated that the molten metal temperature required was not outstandingly high. If the metal came from the cupola spout at 1,380 or 1,400 deg. C. there would be no difficulty in getting it into the 'Lectromelt furnace. The metal would be taken out at about the same temperature. There was no need to approach steel furnace temperatures. As to maintenance charges, he could give no figures, but he thought that with a furnace in regular use over a year the cost of maintenance would be two or three times that of a cupola. Almost any light scrap would be suitable to place on top of the charge. Very light runners would do if nothing else were available.

MR. G. R. SHOTTON thought that Mr. Twigger must be one of the very fortunate people if he had no difficulty with returned scrap. If, as he understood, about 2 cwts. of metal was added and tapped every 10 min., to what extent was the bath being diluted?

MR. TWIGGER emphasised that a great deal of care was taken in segregating different types of scrap. Scrap from each mixture was reallocated to the same mixture. In the case of the centrifugal foundry, all castings from each specification were marked with a distinguishing colour on the base. With regard to the weight of metal in the 'Lectromelt furnace, they started with a 7-cwt. charge at the beginning of the day. Obviously, if the scheme worked as it should, and they took metal out at the same rate as they put it in, the bath ought to remain substantially constant.

Oil-Fired Receivers Suggested

MR. J. J. SHEEHAN argued that if very high temperatures were not needed it hardly seemed necessary to have an electric furnace. The work described could be done in a receiver of either the oil-fired or gas-fired type. It would be instructive to know why Mr. Twigger abandoned receivers and adopted electric furnaces.

MR. TWIGGER explained that he had had some little experience with oil-fired receivers, in the shape of oil-fired crucibles, and had found it possible to maintain metal at the desired temperatures. Yet if it was a question of enabling composition to be modified in any substantial degree his experience was that they were not successful. If a substantial amount of cold metal was put into a crucible furnace it was a very considerable time before correct temperature was re-established. In the case of an oil-fired furnace, which although successfully used by some foundries as a melting unit, and which could also act as a receiver, the losses in holding any appreciable time were inevitably high, and it was difficult to maintain a steady and accurate composition. Mr. Twigger added that their experience over ten years or so, starting with a very small electric furnace and gradually installing larger units, had been in favour of electric furnaces. He did not think that oil-fired furnaces could have been applied so successfully as an electric furnace to the special cupola/electric duplexing method described in the Paper.

Mr. A. G. Robiette said Mr. Twigger and his colleagues were the first in this country to achieve duplexing on a small scale and on a continuous basis with specialised alloys. He thought that very great credit was due to them, for the scheme required careful synchronisation, and the castings required a high degree of control.

Mr. F. C. Pearce said it occurred to him that Mr. Twigger in his Paper had indicated the possible ultimate method of melting cast iron in this country; everywhere, that was to say, except in the light castings industry. That thought might come as a shock, perhaps, to some. When one looked forward and tried to assess what might happen in this country, if not in the immediate post-war years then later on, several things were apparent. In the first place, there was the limited supply of iron ore. Another consideration was economic stringency. Finally, he supposed that every foundryman thought of the day when foundries would not be up backyards but would be of considerable capacity. He visualised a cupola melting between 5 and 10 tons an hr. and the metal running into a 25-ton electric furnace which produced a material which was of high strength, from which machine tools and ordinary castings were made of very thin section, and another electric furnace for alloyed irons taking metal from the 25-ton electric furnace, and there seemed to him to be a great scheme for conservation of materials. Mr. Pearce added that from the practical point of view the electric furnace was far easier to handle than the oil-fired rotary furnace. Moreover, in wartime there would be less difficulty in getting new labour to operate the electric type of furnace than the oil-fired rotary furnace.

Choice of Furnace

Mr. L. W. Bolton said he understood Mr. Twigger to state that the rocking arc furnace was used mainly for melting from the cold special alloys or alloy irons for mixing with cupola metals, and that a three-phase furnace was used entirely for duplexing. He would like to hear why he chose three-phase furnaces rather than rocking arc for duplexing. He would also welcome some information as to the amount of cold material added to the duplexing furnace. Mr. Twigger had mentioned that he did not require a very high temperature, but he suggested that other types of furnaces would not be so efficient as the arc furnace because of taking into solution the cold metal added. Was the addition 5 per cent. of cold material, or higher quantities?

Mr. Twigger, in replying, said it was quite true that larger sizes of rocking arc furnaces were made than those used in his own case. When they came to larger sizes, however, he thought the load factor would be very important in deciding them in favour of a three-phase furnace. Another reason was that in the rocking arc furnace they relied very largely on conduction from the furnace walls to heat up the charge. It would not be easy to arrange a rocking arc furnace for duplexing on the same lines as they had done, for the reason that full advantage could not be obtained from the rocking mechanism. His own impression was that in the larger sizes of furnaces they would almost certainly go to the three-phase furnace either for melting or duplexing. The three-phase furnaces lent themselves very well to pouring in molten metal in the way described, as well as adding solid material through the back door. That could not be done with a rocking arc furnace as at present designed. As to the amount of solid material added, it was usually about 5 to 10 per cent.

Replying to further questions, Mr. Twigger said he did not imagine that the temperatures required for pouring most cast irons would exceed 1,450 deg. C. Obviously, it cost money to increase the temperature, but the increased current consumption for 1,450 deg. C. would not be great. The whole point of his Paper was that these electric furnaces were not used for something that could be readily done in a cupola. They continued to operate cupolas, and could not do without them, but he proposed to keep them on one base material for which there was a large demand and use the electric furnaces for adjusting the composition of materials, of which, perhaps, the tonnage was not so great—in total amount—but the material was of such importance that it must be very strictly controlled. It was very convenient, and he thought overall economical, to melt in a cupola and deal with the material in the manner suggested.

Oil-Fired Rotary Furnaces

Mr. J. Dolphin maintained that oil-fired rotary furnaces had their place in industry. In his opinion the main difficulty with rotary furnaces was that they could not keep a bath of metal hot over a period without losing carbon and silicon. He had, however, worked these furnaces, melting any alloy desired and without very excessive losses and getting the same composition every day from the same mixture put into the furnace.

Mr. Twigger said the furnaces referred to were to his knowledge in successful operation for melting, but he thought they could only be operated to the best advantage where it was possible to dispose immediately of the whole content of the furnace. They had to deal with a continuous unit which he thought placed these furnaces at a disadvantage.

The author was accorded a very hearty vote of thanks for his Paper, which was obviously much appreciated, containing as it does a wealth of actual working data.

Birmingham, Coventry and West Midlands Branch

Paper No. 784

Pearlitic Malleable Cast Irons*

By A. E. PEACE† (Member)

Pearlitic malleable cast irons have been commercially made for the past 15 years, and during the latter part of that time the varieties and methods of production have been increased and improved. These materials have been developed from blackheart malleable cast iron. Reference to blackheart malleable in this Paper must be understood to apply to a material with total carbon content about 2.40 per cent. produced with a completely ferrite matrix and giving physical properties as follows:—Tensile strength, 24 tons per sq. in.; yield strength, 16 tons per sq. in.; elongation, 15 to 20 per cent.; and Brinell hardness, 110 to 120.

It can readily be appreciated that for certain applications blackheart malleable such as described is rather soft and not as strong as desired. The pearlitic malleables are so called because the ferrite matrix of normal blackheart is replaced by pearlite or some other transition structure of the austenite. This may be to a variable extent and material may be produced with an all-pearlitic matrix or only partially so. Where any of the ferrite matrix of blackheart malleable is intentionally replaced by pearlite or other austenite transition structures, such as martensite or sorbite, the material properly falls into the class of pearlitic malleables. As expected from this brief metallographical description, pearlitic malleable possesses greater strength and hardness, but rather lower ductility, than normal blackheart.

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* This Paper was also read before the Lincoln Section.

† Metallurgist, Ley's Malleable Castings, Limited.

For a ready understanding of the various processes of production, it is necessary to refresh one's mind upon the mechanism of the production of blackheart malleable. In view of the extensive literature[1 2 3 4] on this latter subject, it is unnecessary to deal with all aspects, and it will only be treated here as is necessary to produce a satisfactory picture to illustrate the production of pearlitic malleable.

Graphitisation

The manufacture of blackheart malleable commences with a white cast iron, free from graphite, containing all its carbon in the combined form. This material is then submitted to an annealing treatment whereby the carbide is completely broken down, resulting finally in a structure of nodules of free carbon in a ferrite matrix.

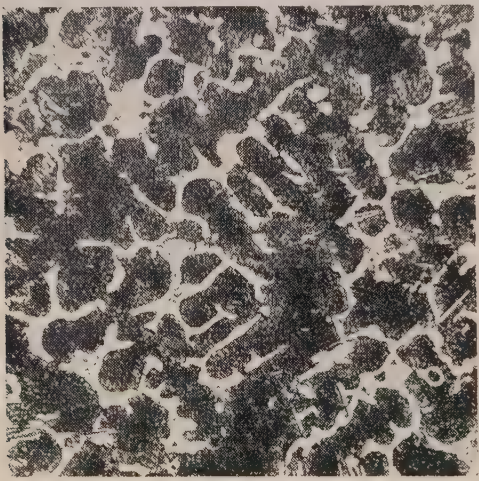

FIG. 1.—WHITE CAST IRON; ETCHED WITH NITRIC ACID. (× 100.)

Considering this process of graphitisation, the steps may be followed by means of equilibrium diagrams. The white iron consists of pearlite and cementite, as shown in Fig. 1. The equilibrium diagrams of Fig. 2 cover both the metastable (iron carbide) and stable (graphite) systems. Some modifications are necessary in the light of more recent research work, but as the present purpose is to create a picture of the graphitising process, greater precision is not essential. Now, as the white iron is heated above the critical point, the pearlite is transformed to austenite with a carbon content of about 0.9 per cent. As the temperature is increased, the austenite absorbs carbon from the cementite, maintaining its saturation at any temperature in accordance with the line Acm in the metastable system, so that at 900 deg. C. the austenite will contain about 1¼ per cent. carbon. Reference is made to this temperature as it conforms with commercial practice and is convenient for demonstration purposes. Now, whilst this increase in temperature is being accomplished, the saturated austenite precipitates some of its carbon in the free state as graphite. This graphite is in the shape of nodules and is referred to in malleable practice as temper carbon.

There are thus two reactions taking place; on the one hand, free carbon is being precipitated from the austenite, denuding it of its carbon, and, on the other hand, the austenite is making good this loss and attempting to maintain its saturation by dissolving carbon from the cementite. As the temperature of 900 deg. C. is maintained, these reactions proceed, more free carbon being deposited at the expense of cementite, until equilibrium is reached and all the carbon in the cementite has been dissolved, when the structure consists of nodules of free carbon and saturated austenite. The austenite now contains some 0.95 per cent. carbon and is saturated with respect to graphite. It should be understood that at the commencement of the graphitising process the austenite is saturated under metastable conditions (line Acm). As graphitisation proceeds, there is obviously a carbon gradient through the austenite, the solid solution adjacent to a cementite particle being saturated, according to Acm and that adjacent to a graphite nodule being saturated (with a less amount) according to Atm.

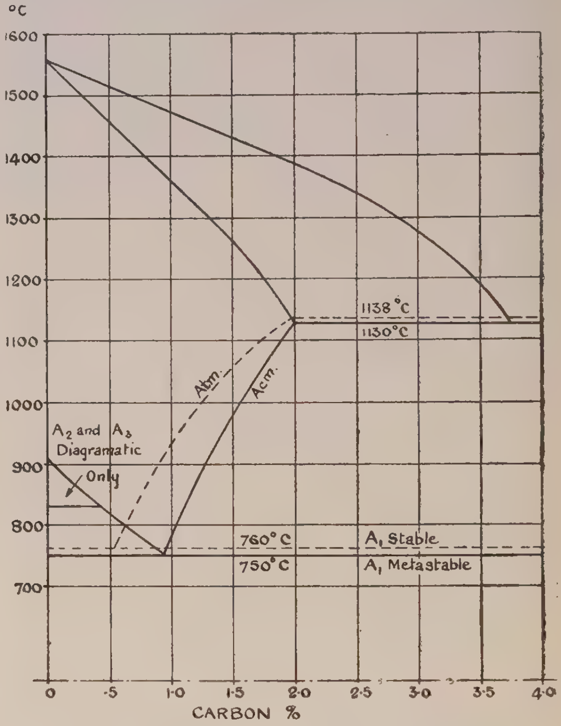

FIG. 2.—BENEDICK'S EQUILIBRIUM DIAGRAM; MODIFIED BY SCHWARTZ FOR AN IRON-CARBON ALLOY CONTAINING APPROX. 1 PER CENT. SI.

This gradient is a necessary feature of carbon migration. When all the cementite has been destroyed the austenite will come to a uniform saturation under stable conditions. Continued holding will produce no further change in the amount of free carbon deposited nor in the carbon content of the austenite. Now if the temperature is slowly lowered the austenite will be saturated with less carbon, according to the line E′S′, and more free carbon will be precipitated until the critical point on cooling is reached. At this stage the austenite contains about 0.5 per cent. carbon and transforms to pearlite, which will graphitise completely if the temperature be held just below the critical, or as is more usual in practice if a very slow rate of cooling, say 5 deg. C. per hr., be maintained down to some 20 or 30 deg. below the critical. There is then a complete ferrite structure, with temper carbon nodules as illustrated in Fig. 3.

Mechanism of Crystallisation

It is customary to refer to the graphitisation taking place whilst obtaining equilibrium at the maximum temperature as first stage graphitisation and the graphitisation on cooling to below the critical as second stage graphitisation. Whilst there is a very considerable literature on the subject of graphitisation, the matter is exceedingly difficult of investigation, and the actual mechanism is but poorly understood. It is clear that a number of steps are involved. There has to be a dissociation of the iron and carbon of the carbide, a solution of this carbon in the austenite, a crystallisation of graphite, and a migration of carbon to the centres of crystallisation.

FIG. 3.—BLACKHEART MALLEABLE CAST IRON; ETCHED WITH NITRIC ACID. (× 100.)

It is not known how a nucleus of crystallisation is initiated. Schwartz[5] has demonstrated that the graphite centres form at the interface of the carbide particles and the austenite. A hot concentrated alkaline picrate etch was used upon fully graphitised material. This reagent differentially attacks the ferrite and shows up the original pattern of the austenite and free cementite due, Schwartz suggests, to the etch distinguishing between varying silicon concentrations. Morrogh[6] has shown and discussed graphite nucleisation by sulphide particles, and this is perfectly compatible with nucleisation at the carbide surface since the presence of sulphides at grain boundaries is quite likely. It is also probable that internal stresses assist in the birth of nuclei. Wells[7] has shown that graphite can be formed both from the austenite solid solution and directly from free cementite. Experience suggests that in malleable cast irons the graphite centres preferentially form from the austenite.

The number of centres of crystallisation and therefore the number of temper carbon nodules which are formed has a considerable effect upon the rate of graphitisation. With many nodules graphitisation proceeds in more places at one time, and migratory distances are reduced so that completion is obtained more quickly. Heating slowly to the annealing temperature favours the formation of numerous nodules,[8] as also does high initial soaking temperature.[9] It is also known that white iron heated to temperatures of 900 to 1,000 deg. C., and rapidly cooled, produces more numerous nodules upon annealing, which it has been suggested may be due to a spheroidising of some of the cementite particles when heating to the annealing temperature.[10]

Returning now to a consideration of the two stages of the graphitisation process and assuming one has carried out the first stage by holding sufficiently long at a temperature above the critical, the second stage is now only completed by slow cooling through or holding at a temperature just below the critical. Completion of this second stage can clearly be prevented by giving insufficient time for it to take place. In practice this is accomplished by cooling quickly through or reducing the holding time around the critical.

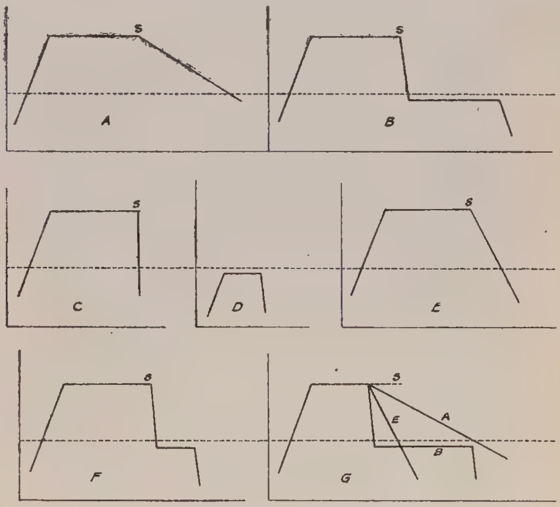

FIG. 4.—DIAGRAMMATIC TIME AND TEMPERATURE CYCLES.

Annealing Cycles

The diagrams shown in Fig. 4 illustrate a variety of annealing cycles. The abscissæ are time and the ordinates temperature. In each diagram the broken line indicates the critical temperature. Diagram A is a typical annealing cycle for producing blackheart malleable. It will be seen that there is a holding at the maximum temperature to the point denoted by S, when all the cementite has disappeared and equilibrium is established. The cooling is then very slow through the critical, permitting completion of second stage graphitisation, and the resulting product has a ferrite matrix. Diagram B shows another commercial method of producing the same result. Equilibrium is established at point S, and the cooling is rapid to below the critical, where the metal is held for a sufficient time to complete second stage graphitisation and yield a ferrite matrix. This holding may also take place in steps as recommended by Ziegler.[11] In diagram C is illustrated a rapid cooling from the point S by quenching. Whilst equilibrium was established at S and therefore there was no free cementite in the metal at that point, the extremely rapid cooling would prevent second stage graphitisation, and the quenching could be even so drastic as to retain the matrix in a martensitic condition. In diagram E, a slower rate of cooling is indicated, although in this case much faster than in A, and whilst some second stage graphitisation would take place, the matrix structure would be largely composed of finely laminated pearlite.

A somewhat similar result would be obtained by the treatment shown in F, where rapid cooling has been followed by a short hold at just below the critical which would give time for the austenite to transform to a fine pearlite structure. It will be realised that, in the treatment shown in diagram C, the high-carbon martensitic structure produced by quenching would have but very poor shock resistance and a further heat-treatment can be carried out as illustrated in D, which consists of a reheat and holding period just below the critical, resulting in a sorbite or pearlite structure. It will be appreciated that after establishing equilibrium at the higher temperatures, the rates of cooling and the holding periods below the critical can be varied within considerable limits, and this variation not only affects the transition stage of austenite which is reached, either martensite, troostite, sorbite or pearlite, but also can permit a certain amount of second-stage graphitisation to take place with the production of ferrite, depending upon the rates of cooling and times of holding. One can thus obtain an infinite variety of matrix structures and vary the physical properties produced.

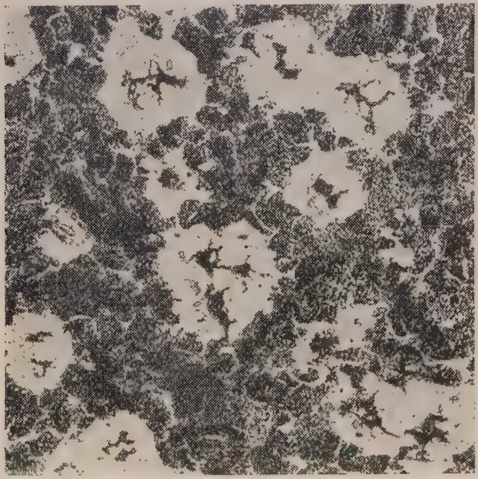

FIG. 5.—" BULLSEYE " STRUCTURE; ETCHED WITH PICRIC ACID. (× 100.)

In diagram G it will be seen that the holding time at the maximum temperature has not been continued until equilibrium has been reached at the point S. and in this case, when cooled from the maximum temperature, the metal will contain a proportion of eutectic cementite which has not been destroyed. The subsequent cooling will substantially affect only the condition of the matrix in which the undestroyed carbides are distributed, and this matrix can be again produced in any desired structure by using variations in cooling rates. For example, A and B, indicated in diagram G, are the types of cooling which will produce a ferrite matrix. Some idea of the range of structures obtainable with the heat-treatments indicated may be gathered from a few illustrations.

Fig. 5 shows a " bullseye " structure in which the matrix is pearlite with a considerable amount of ferrite forming lakes around the temper carbon nodules. This is typical of a rate of cooling (diagram E of Fig. 4) intermediate between the very slow rate which is used to complete second-stage graphitisation and the air quench which practically prevents any second-stage graphite being formed. In Fig. 6, at high magnification, is shown the structure produced by cooling from 930 deg. C., at a rate of approximately 7 deg. C. per minute. The matrix is exceedingly fine pearlite, and it will be noticed that traces of ferrite exist, showing that some slight graphitisation has taken place even with this rapid rate of cooling. Fig. 7 illustrates the arrest of first-stage graphitisation, as indicated in diagram G of Fig. 4. This specimen was annealed for 4 hrs. only at 900 deg. C., and oil-quenched. Appreciable quantities of eutectic cementite remain in a matrix of pseudo-martensite.

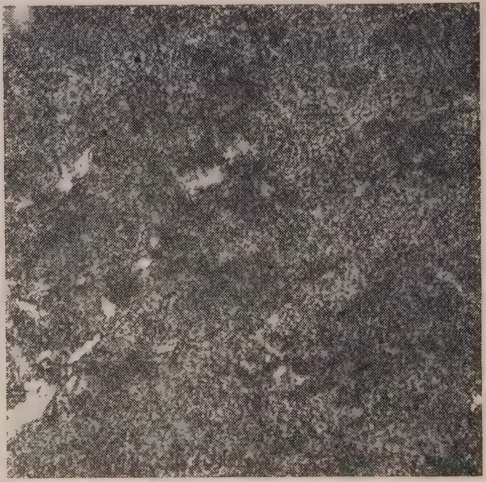

FIG. 6.—COOLED FROM 930 DEG. C., AT 7 DEG. PER MIN.; ETCHED WITH PICRIC ACID. (× 500.)

Austempering

It will have been noticed that among the heat-treatments described some have a similarity to the quench and temper used in hardening steels. During the last few years a new hardening treatment for steels has been developed, known as "austempering." Instead of quenching into water or oil, followed by reheating to draw or temper, the metal is quenched into a liquid bath (*e.g.*, molten lead), held at a definite suitable temperature. The hardness obtained is determined by this temperature, provided a minimum holding time is given in the bath. This treatment on steels produces improved toughness. Cowan[12] and also Walker[13] have published some results on pearlitic malleable produced by "austempering," but there are insufficient data to determine whether improved properties are obtainable. The method is, however, of great interest and warrants further investigation.

Carbon Re-solution Process

It has long been known that when blackheart malleable is reheated above the critical temperature temper carbon will go back into solution, the amount redissolved depending upon the temperature and time. Advantage has been taken of this to produce pearlitic malleable, which differs from the types previously described by reason that the carbon goes into solution and diffuses first of all along the grain boundaries, so that after a short time above the critical a network structure is obtained in a ferrite matrix.

It is, of course, possible to hold the metal above the critical for a sufficiently long time to obtain diffusion through the grains, in which case structures can be obtained similar to those indicated under arrested anneal processes. However, in this reheat method it is usually desired to go no further than the production of the network structure which is first obtained in the martensitic condition by quenching and subsequently tempered to produce sorbite. Fig. 8 shows such a structure. The matrix is ferrite with sorbite forming a network around the grain boundaries. A concentration of sorbite will be observed surrounding the temper carbon nodules, and evidence will be seen of diffusion of carbon through the grains. The re-solution of some of the free carbon by reheating above the critical is also used to produce surface hardening by means of flame and induction heating. By this process a martensitic structure is obtained in the surface, of hardness equivalent to case-hardened steel.

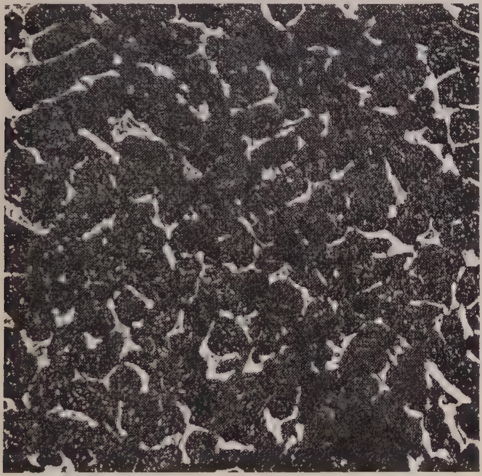

FIG. 7.—INCOMPLETE EQUILIBRIUM ABOVE A; ETCHED WITH NITRIC ACID. (× 100.)

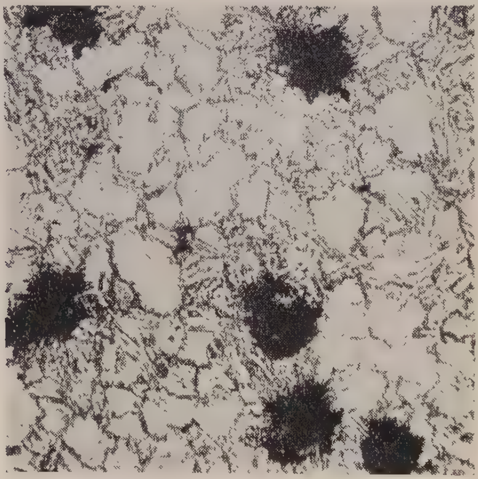

FIG. 8.—REHEATED ABOVE A; ETCHED WITH PICRIC ACID. (× 100.)

Heat-treatment Furnaces

In the processes already described it is obvious that precise control of heat-treatment is needed, particularly of cooling rates. When operating with batch-type ovens handling large charges, it is not usually possible to obtain cooling rates as fast as required. This has led to further development of small-size batch ovens and of larger capacity continuous furnaces. In these types of furnaces a controlled atmosphere is secured, so that the work can be processed without resorting to packing in boxes and without the lag inseparable from such a method. In some treatments the work is discharged from the furnace into a quenching bath, in others into an air quench which may be accelerated by air blast. A separate furnace is then used for the further heat-treatment below the critical.

It is appropriate here to deal with annealing atmospheres, and this warrants, first, a consideration of the effect of gases in the metal.

Effect of Gases in the Metal

Hydrogen.—Molten iron has a great solubility for hydrogen, but this is very materially lower in the solid. However, minute quantities are known to retard graphitisation.[14] It is therefore fortunate that hydrogen is expelled early during the annealing process and no ill-effects are noticeable. Interesting work[15] has recently been carried out which shows that treating the molten iron with hydrogen followed by a low-temperature heating of the white cast iron results in greatly increased nucleisation, and consequently more rapid graphitisation.

Oxygen.—Most manufacturers of blackheart malleable suspect oxygen as having decisive effects upon graphitisation, but there is little concrete evidence available. There is some information[16] that it may accelerate graphitisation by nucleisation.. There is also a possibility that oxide films may retard graphitisation. It is established that oxygen-contaminated cementite is stable under annealing conditions and will not dissociate into iron and carbon.

Nitrogen.—Nitrogen is usually regarded as inert and unlikely to affect graphitising reactions. However, it has recently been indicated[17] that nitrided white iron graphitises rapidly, due to nuclei increase, and also that nitrogen introduced into the melt causes a response to low-temperature preheating of the white iron in a similar manner to that previously indicated under hydrogen.

Effect of Atmosphere on Graphitisation

Hydrogen.—Annealing in an atmosphere of hydrogen, or gases which will yield hydrogen by decomposition at annealing temperatures, retards graphitisation, possibly because this prevents the elimination of hydrogen from the metal. Wells[7] has shown that graphitisation in a hydrogen-hydrocarbon atmosphere is slower than in vacuo.

Oxygen.—Oxygen by decarburisation gives at once a $CO.CO_2$ mixture, and such mixtures are said to accelerate annealing, although White and Schneidewind[18] consider that, even though varied from oxidising to reducing, they have no direct effect. However, the indirect effect is pronounced and annealing times are prolonged when an oxidising atmosphere exists. This causes surface decarburisation, which reduces the quantity of graphite nodules formed in the surface metal, so that both first-stage and second-stage graphitisation are restrained. This is of considerable importance in pearlitic malleables, since the decarburisation effect may cause the retention of eutectic cementite in the surface and can also result in complete removal of carbon in the skin and thus prevent surface hardening if this treatment is desired.

Cowan[19] has discussed this matter very fully, and suggested that the atmosphere should be rich and strongly carburising in the early stages of anneal and leaner in the later stages. In this country much work has been done on the subject during the war and when publication can be made it will be found that great advances have been achieved. In Fig. 9 carbon gradient curves are given for three different casts of malleable annealed under identical conditions. Total carbon content is related to section measured from the surface. These curves are typical for blackheart type malleable exposed during annealing to "incidental" oxidising atmospheres. The extremely sharp fall in carbon content is characteristic, and its position is moved to left or right as the atmosphere is less or more oxidising. So far consideration has only been given to pearlitic malleables produced by means of variation of heat-treatment.

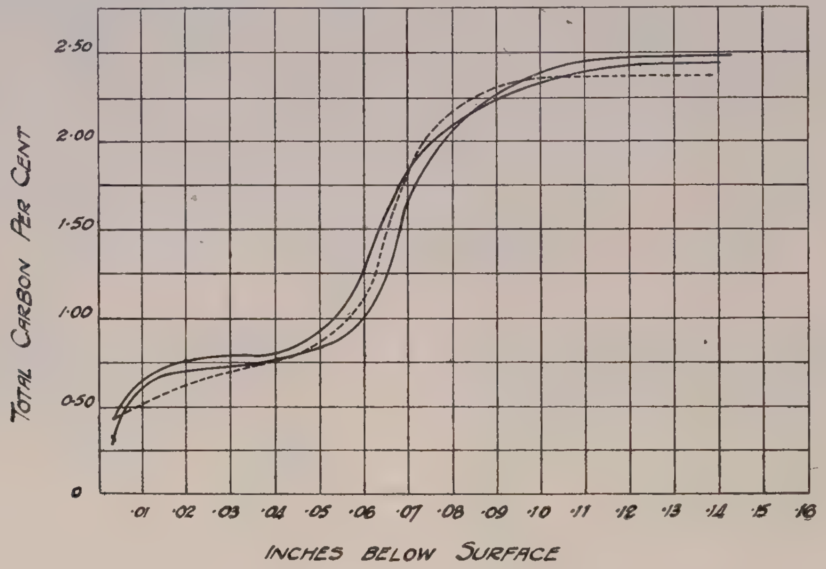

FIG. 9.—CARBON GRADIENT CURVES.

Use of Alloys

The arresting of second stage graphitisation can, however, be effected by the use of alloying elements. Those which are suitable are naturally the ones which retard graphitisation. Fortunately the retarding

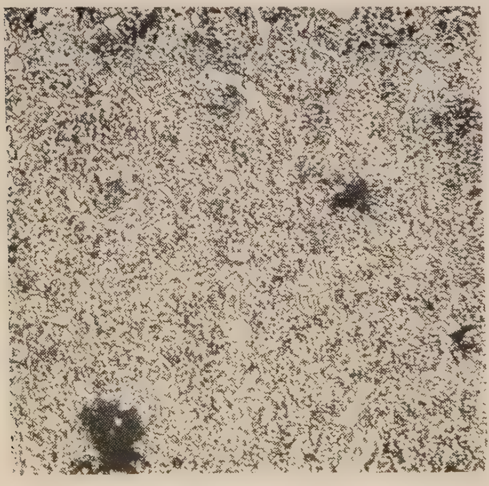

FIG. 10.—CHROMIUM PEARLITIC MALLEABLE; ETCHED WITH NITRIC ACID. (× 100.)

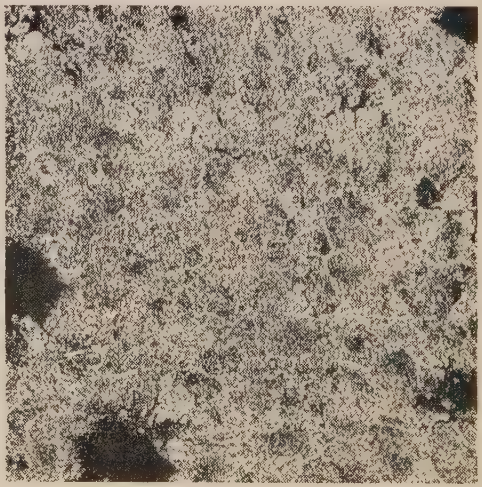

FIG. 11.—MANGANESE PEARLITIC MALLEABLE; ETCHED WITH PICRIC ACID. (× 100.)

elements generally affect second stage graphitisation more markedly than first stage graphitisation, so that it is possible to obtain equilibrium at the maximum temperature whilst preventing the attainment of equilibrium conditions during cooling through or holding below the critical.

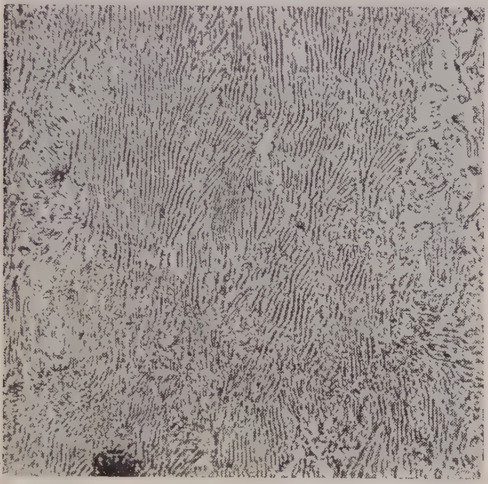

FIG. 12.—SAME SPECIMEN AS FIG. 11; ETCHED WITH PICRIC ACID. (× 500.)

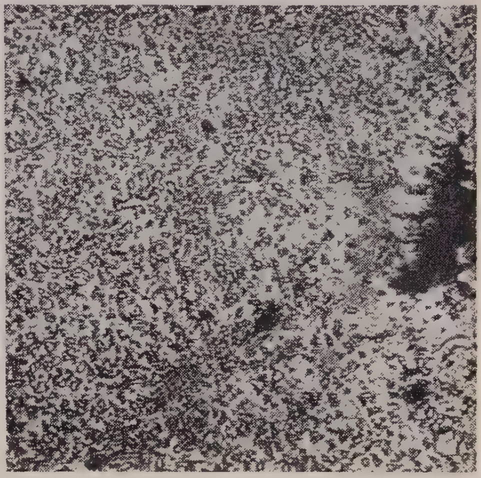

FIG. 13.—SPHEROIDISED SPECIMEN; ETCHED WITH PICRIC ACID. (× 500.)

An investigation was carried out some years ago by Rebecca Hall[20] upon the use of chromium, and it was found desirable to increase the silicon content with the chromium additions. Even so it is unusual for chromium pearlitic malleable to be produced without some proportion of free cementite being retained. However quite reasonable ductility, as determined by measurement of elongation, is achieved, and high wear resistant properties are ascribed to this type of product. The structure of a chromium pearlitic malleable is illustrated in Fig. 10. Much free cementite persists, but the particles are generally small and rounded. The matrix is spheroidised, a usual feature with chromium metal. This example contained 0.40 per cent. Cr and 1.68 per cent. Si. The amount of added silicon is 1¾ times the chromium content, and much greater than recommended by Rebecca Hall, who appeared to be guided by the physical properties obtained without relation to the micro-structures.

Vanadium has been used in quantities of the order of 0.1 per cent., and this element effectively prevents decomposition of the carbide, but the cementite structure is so massive that shock resistance is poor, and it does not appear that much commercial use has been made of this alloy. Manganese has been utilised in quantities from ½ to 1 per cent. above the amount normally present in blackheart malleable. Manganese has a milder effect than chromium, and there is no difficulty in completing first stage graphitisation, whilst the second stage is retarded even under conditions of

TABLE I.—*Typical Mechanical Properties of Pearlitic Malleable Cast Iron.*

Production class.	Structure type.	Tensile strength. Tons per sq. in.	Yield point. Tons per sq. in.	Elongation. Per cent.	B.H.N.
Mn	Bullseye	30	18	10	150
,, ...	Lamellar	35	21	6	180
Mn Cu	Lamellar	36	22	5	190
Mn	Spheroidal	31	22	16—18	179 (a)
,, ...	,, ...	36	25	12—14	191
,, ...	,, ...	40	28	9—11	207
,, ...	,, ...	45	31	6—8	217
Ni Mn	Sorbite	35	22	6	210
,, ...	,, ...	37	24	6	210
,, ...	,, ...	39	26	5	210
Arrested..	,, ...	39	24	4.5	190
,, ...	,, ...	49	28	3	230
,, ...	,, ...	54	36	1	350 (a)
Ni Cr	,, ...	40	27	8	200 (a)
Si Mo	,, ...	35	31	3.5	245 (b)
Re-heated	,, net	31	22	10—14	170—190 (a)
Si Cr	Free carbides	35	24	3	210
Va	,, ,, ...	31	28	3.5	211 (a)

(*a*) Symposium on Pearlitic Malleable Cast Iron, A.S.T.M., 1936.
(*b*) *Cast Metals Handbook*, 1940 Edition, A.F.A.

very slow cooling. Fig. 11 shows the pearlite structure retained with manganese upon slow cooling. Only very small quantities of free ferrite are present. The pearlite is well laminated, as shown in Fig. 12, which is from the same specimen. A tendency towards spheroidisation is noticeable. To obtain a completely spheroidised structure it is necessary to cool rapidly through the critical temperature and then hold just below for a period of some hours. The structure produced is shown in Fig. 13.

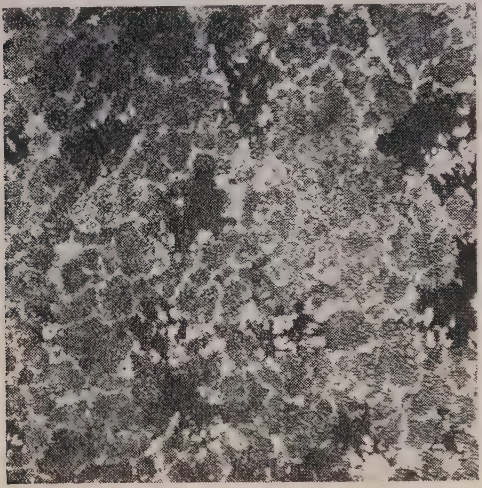

FIG. 14.—NICKEL ABSENT; ETCHED WITH PICRIC ACID. (× 100.)

Molybdenum has also been used in quantities of the order of 0.2 to 0.6 per cent., usually with some slight increase in silicon content. The effect of molybdenum is more drastic than manganese, but less so than chromium. There is a further advantage attached to the use of retarding elements in that after air or oil-quenching from the annealing temperature, reheating just below the critical can be used to produce a spheroidal structure of the carbide, which gives enhanced ductility. The spheroidising treatment requires a long holding time, and is not readily possible without alloying elements, as otherwise second stage graphitisation proceeds so rapidly as seriously to reduce the combined carbon content.

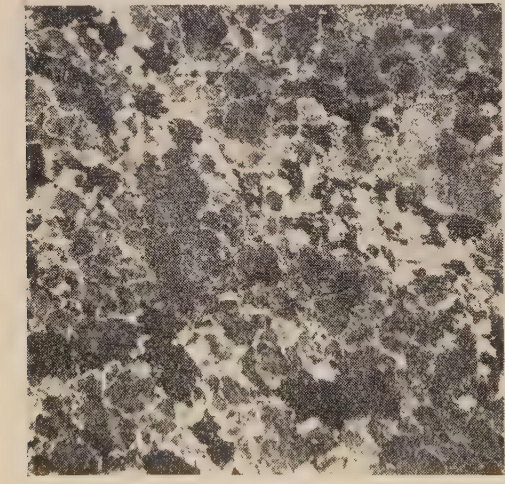

FIG. 16.—NICKEL, 0.78 PER CENT.; ETCHED WITH PICRIC ACID. (× 100.)

Alloys can also be used for their effect upon the matrix structure as distinct from the effect upon graphitisation, and in this respect they may also render the metal more sensitive to further heat-treatment. Copper has been used in this manner, but its effect is

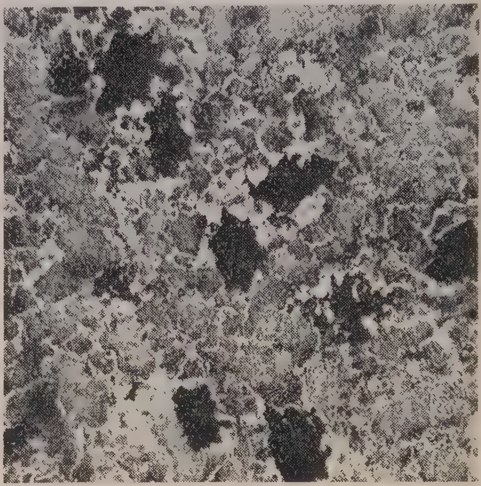

FIG. 15.—NICKEL, 0.33 PER CENT.; ETCHED WITH PICRIC ACID (× 100.)

very mild, only slightly increasing the tensile and yield strengths. Nickel has a more pronounced effect, and gives appreciable increase in tensile strength and yield without materially affecting the hardness of ductility. Schwartz[21] has shown that small quantities of nickel destroy the effect of silicon in accelerating graphitisation, and also that the graphitising process appears to take place by some different mechanism. The graphitisation accelerated by silicon proceeds by

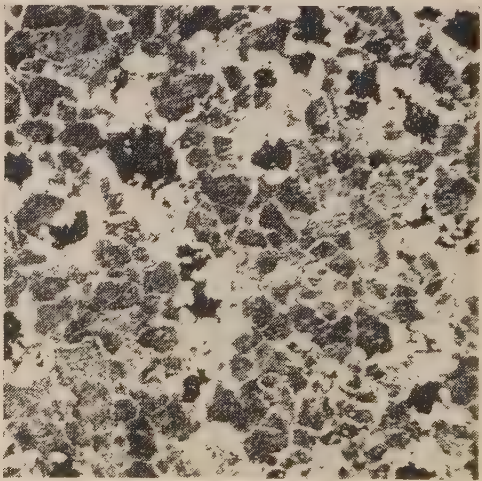

FIG. 17.—NICKEL, 1.84 PER CENT.; ETCHED WITH PICRIC ACID (× 100.)

increase in the size of the graphite nodules, whereas in the case of nickel it appears to progress rather by increase in the number of nodules.

There is a further effect of nickel in that the second-stage graphitisation proceeds further with increasing quantity of nickel, so that structures which would normally be all pearlitic contain appreciable quantities of ferrite. This ferrite no doubt accounts for the maintenance of ductility, whilst the higher strengths obtained are due to the carbide being present in the sorbitic rather than pearlitic form.

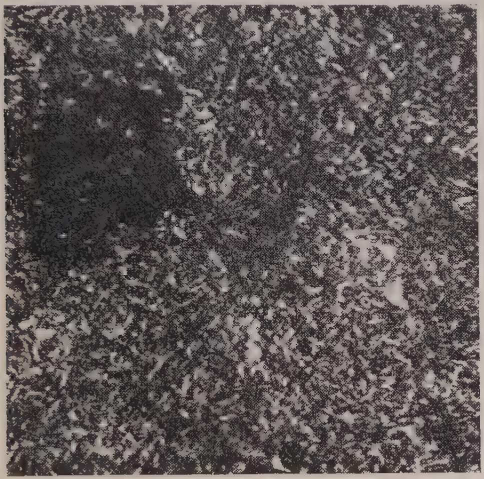

FIG. 18.—NICKEL, 0.78 PER CENT.; OIL QUENCHED FROM 780 DEG. C.; DRAWN AT 500 DEG. C.; ETCHED WITH PICRIC ACID. (× 500.)

The nickel alloyed material is also more sensitive to subsequent heat-treatment. Figs. 14 to 17 illustrate the effect of nickel in quantities increasing from nil to 1.84 per cent. The samples were all from one melt of metal and were annealed together. It will be observed how the amount of ferrite increases with nickel content. In Fig. 14 the carbide structure is pearlite, but in Figs. 15 to 17 it is sorbite.

Physical Properties

A fairly comprehensive survey of the varying tensile properties obtainable with pearlitic malleable cast iron are given in Table I. Under the heading of Production Class is given the controlling medium by which the material is produced, and under Structure Type is indicated the particular feature of the micro-structure. The first two manganese class and the manganese copper are produced by a slow-cooling method, whereas the next group of manganese metals with the spheroidal structure are produced by rapid cooling from the annealing temperature, followed by a spheroidising treatment just below the critical. It is apparent that this type of structure gives a better ratio of ductility to strength. The nickel-manganese irons were produced by slow-cooling methods, and show the slightly improved tensile and yield stress obtainable with nickel additions. The arrested anneal material was produced by rapid cooling from the annealing temperature, and in the last example shown an oil-quench was used. In the case of the reheated example, as mentioned previously, the structure can be taken to a greater degree of diffusion of redissolved carbon with increase in tensile strength, but reduction in ductility.

The figures shown in Table II are extracted from Rebecca Hall's Paper mentioned previously. It should be pointed out that in addition to the chromium content, the silicon was increased by an amount equal to one-half to three-quarters of the added chromium. The yield stress and hardness are increased with the chromium additions and the ductility reduced. In the next Table III the tensile properties with increasing nickel content are given. The nickel, as pointed out previously, strengthens the material without seriously decreasing the ductility, and also considerably improves the strength upon hardening. It may be noticed here that the hardened and tempered material shows little variation in the yield stress and elongation, and this appears to be a feature of heat-treated pearlitic malleables.

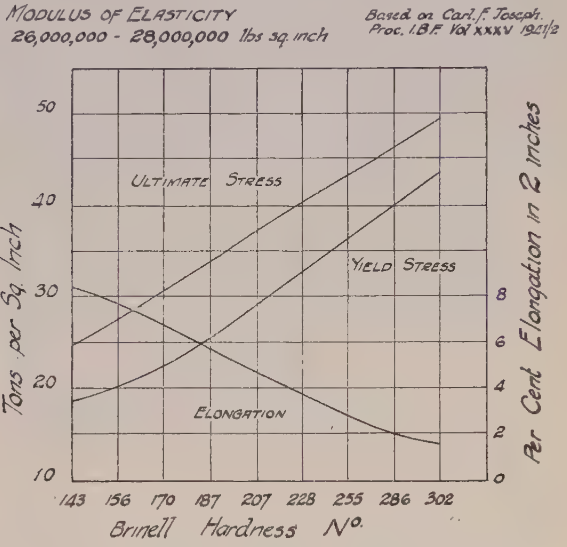

FIG. 19.—TYPICAL PHYSICAL PROPERTIES OF PEARLITIC MALLEABLE CAST IRON.

Fig. 18 shows the structure of the hardened and tempered metal containing 0.78 per cent. Ni, in which the matrix is pseudo-martensite. Fig. 19, a reproduction of a graph by Joseph,[22] again shows a range of tensile properties obtainable, and these are related to hardness number. These data are from unalloyed material, rapidly cooled from the annealing temperature and subsequently heat-treated just below the critical for varying lengths of time. The physical properties of hardened and tempered pearlitic malleable are shown in Fig. 20, where the hardness and tensile properties are related to tempering tempera-

TABLE II.—*Tensile Properties of Chromium Pearlitic Malleable Cast Iron.*

Cr. Per cent.	Tensile strength. Tons per sq. in.	Yield point. Tons per sq. in.	Elongation. Per cent.	B.H.N.
0.22	31.3	18.9	11.0	175
0.37	34.3	22.0	9.5	179
0.56	35.9	23.4	6.0	201
0.84	35.7	26.4	4.0	213
1.08	34.2	27.7	3.0	223

Extract from "High Strength and Wear-Resistant Malleable Cast Iron," by Rebecca Hall, Trans. A.F.A., Vol. 41 (1933).

tures. Once again it is seen that the yield stress and elongation show little variation through the range of heat-treatments employed. The tensile properties determined from stress-strain diagrams are shown in Table IV, compared with those of blackheart malleable. The proportional limit is very appreciably higher in pearlitic malleable, as also is the modulus of elasticity.

It may be noted that in Fig. 19 Joseph gave a range of 26,000,000 to 28,000,000 lbs. per sq. in. for the modulus of elasticity. Little work has been done upon the fatigue properties of pearlitic malleable, but some results are shown in Table V compared with examples of cast iron, wrought mild steel and nickel steel. Generally, in ferrous materials the endurance ratio, that is, the ratio of the fatigue limit to the tensile strength, is of the order of 0.5, and it is surprising to find the ratio only 0.39 in this example of pearlitic malleable. As further data become available, it will be possible to confirm whether this is characteristic of these materials.

TABLE III.—*Tensile Properties of Nickel Pearlitic Malleable Cast Iron.*

Ni. Per cent.	Tensile strength. Tons per sq. in.	Yield point Tons per sq. in.	Elongation. Per cent.	Diamond hardness.
		In Annealed Condition.		
Nil	35.04	21.00	6.0	213
0.33	34.80	21.58	5.5	212
0.78	36.85	23.46	5.5	214
1.84	38.65	25.74	5.0	210
		Hardened and Tempered.		
Nil	52.43	44.35	0.5	351
0.33	54.80	44.00	0.5	358
0.78	58.18	43.57	1.0	347
1.84	60.00	43.70	1.0	343

It is noticeable that the notch sensitivity is much less in the pearlitic malleable than in the case of the wrought steels, and this falls somewhat in line with experience obtained with cast irons where the reduction due to notch is from zero up to some 10 per cent. No data appear to have been published upon the impact testing of pearlitic malleable, but in an example with a tensile strength of 35 tons per sq. in., Izod values of 8 to 10 ft.-lbs. have been recorded. This compares with 14 to 16 ft.-lbs. for ferritic blackheart malleable.

TABLE IV.—*Tensile Properties from Stress-Strain Diagram.*

Property.	Pearlitic malleable.	Blackheart malleable.
Ultimate stress. Tons per sq. in.	36.15	24.00
Yield stress. Tons per sq. in.	19.70	14.50
Proportional limit. Tons per sq. in.	12.50	8.00
Elongation. Per cent in 2 in. ..	5.0	15.0
Modulus of elasticity. Lb. per sq. in.	28,250,000	25,000,000

It would appear that with other structures, such as the spheroidal and ferrite-sorbite, higher impact values might be obtained. Impact testing of materials of this order of shock resistance by means of the standard 10 mm. square notched bar using the Izod machine, does not appear to be sufficiently discriminating, and is probably too sensitive to imperfections of the notch surface satisfactorily to illustrate the differences existing in the various types of pearlitic malleable. Kikuta[23] used a 30 kg. Charpy machine and a 15 mm. square bar with a 2 mm. notch upon blackheart malleable, and obtained figures of the order of 25 ft.-lbs. With various heat-treatments he obtained a range of results from 4 to 45 ft.-lbs., and a sufficient uniformity in duplication which suggests that larger size bars with reduced notches may be useful in comparing the shock resistance of pearlitic malleables.

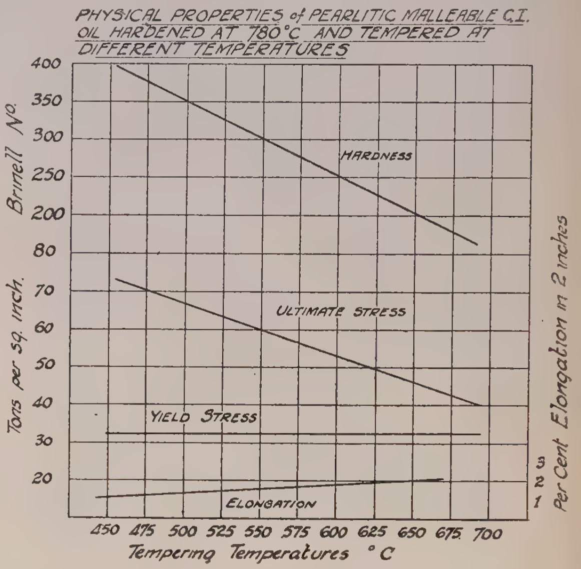

FIG. 20.—PHYSICAL PROPERTIES OF HARDENED AND TEMPERED PEARLITIC MALLEABLE IRONS.

It has now been seen that a great variety of physical properties is obtainable with pearlitic malleables, and that they are all characterised by high tensile and yield strength, high modulus of elasticity and fatigue endurance limit. The wear resistance is imperfectly indicated by the Brinell hardness, and claims are made that wearing properties are superior to those expected from a consideration of indentation hardness tests. Machineability varies with type, but generally can be regarded as superior to steels of similar Brinell hardness.

TABLE V.—*Comparison of Fatigue Properties.*

Material.	Tensile strength. Tons per sq. in.	Endurance limit. Tons per sq. in.		Endurance ratio.	Notch reduction.
		Plain.	Notched.		Per cent.
Pearlitic malleable	35.1	13.7	11.3	0.39	17.5
Cast iron(*a*)	15.8	8.9	8.9	0.56	Nil
Mild steel (*a*)	34.3	17.2	11.4	0.50	33.7
Nickel steel	51.5	22.5	13.5	0.44	40.0

(*a*) Cornelius and Bollenrath, "Die Giesserei," Vol. 23, No. 10.

Applications

The qualities which recommend pearlitic malleables to their numerous applications are essentially high strength, great rigidity, wear resistance, high fatigue properties, and response to full and local hardening. Pearlitic malleables are utilised for elevator and driving chain links and sprockets, stoker parts, machine tools, liner plates and numerous automobile details, such as axle housings, differential carriers, brake drums, camshafts, crankshafts, connecting rods, gear blanks, pistons and piston rings. It would appear that the future of these materials lies largely in the appreciation of manufacturers of the difficulties of production and of the necessity for modern heat-treatment furnaces capable of accurate temperature control, so that results can be reproduced and uniformity of product maintained.

Acknowledgments

Acknowledgment is made to Ley's Malleable Castings Company, Limited, for permission to publish much of the information included in this Paper, to Mr. W. T. Evans for his stimulus during the early days of pearlitic malleables, and to Mr. W. H. Smith and Mr. H. Greatorex for their great help in experimental work over a period of years, and also in the production of the present illustrations.

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Birmingham, Coventry and West Midlands Branch **Paper No. 785**

The Production of Air-Cooled Cylinders

By T. H. TAFT* (Member)

Automobile castings, as a whole, are known to be amongst the most difficult castings to produce, and in this specialised branch of the foundry industry, air-cooled cylinders have their own very special problems. One of the main difficulties (due to the intricate shape of the castings, as shown in Fig. 1), is that practically all moulds have to be stoved. It is not inferred that the methods adopted to produce air-cooled cylinders by the company with which the author is associated are necessarily the best. He has been extremely interested in the methods[1] adopted by American foundries producing aluminium air-cooled cylinders of an intricate type, but allowing for the very high rate of production which is required, to make the cylinder described later would mean that sand and drying costs would be so high as to be prohibitive. These aluminium cylinder heads are used on Wright's radial engines, and consist of very fine pitch fins up to 3 in. deep. In the American method of manufacture, 750 pins are placed in each half-mould, and the complete mould weighs over 400 lbs. The time for drying is given as 7 hrs. at 450 deg. F. (230 deg. C.). If a similar method were adopted for making the side valve cylinder, the sand mound would weigh about 120 lbs., and would take about 5 to 6 hrs. to dry. What troubles would arise from the gas evolved, due to the higher pouring temperature of cast iron, it is difficult to say, but in view of past experience, trouble could be expected from this source.

Pattern Equipment

Good castings can never be made quickly from indifferent pattern equipment, and it cannot be overemphasised that air-cooled cylinder patterns must be first class. A master pattern is made usually in pine, as this wood tends to give less trouble from warping; aluminium, brass or bronze castings are finished off for production patterns. An example of the fine limits required, shown in Fig. 2, is a 3-in. dia. bore cylinder with $\frac{1}{4}$-in. wall, having $1\frac{1}{2}$-in. fins, which are $\frac{1}{8}$ in. at the root and $\frac{1}{32}$ in. at the tip, and give a taper for drawing of $\frac{1}{32}$ in. This is not too bad, but at the joint line, where the draw is 3 in., 0.011 in. taper to the inch, and half-way to the edge 2-in. draw, 0.007-in. taper to the inch is pretty fine work. When finishing off the pattern, great care obviously has to be taken, to avoid undercuts.

The foregoing may not be so important for hand-moulded work, which is usually well rapped and knocked down, but, where dimensional accuracy is required, personal opinion is that machine moulding is essential. Stripping plates are never used unless every other method has failed to give the required result. These patterns or coreboxes are constructed so that the fins are made separately from the body, and fixed together, as shown on Fig. 3. with parts dismantled. The body, which usually forms the radius at the bottom of the fins, is also held together by a series of spacing pieces; both these parts are separate from one another. Each part, however,

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* Foundry Manager, Idoson Motor Cylinder Company, Limited.

must fit into the other with the minimum clearance to avoid sand getting between the joints.

Fig. 4 shows corebox complete with sand core. The advantages are that the sand can be rammed to the maximum density, the pattern or corebox does not require rapping before drawing, and a core true to size is obtained. The claim made for this type of equipment that unskilled labour can be used has not been substantiated. It has been proved that all other things being equal, the use of stripping plates has not increased production. Some manufacturers insist on jigging off fins for the first machining operation, and occasionally, under these circumstances, recourse has to be made to stripping plates.

The preparation of this type of equipment is both tedious and expensive, and it is very apt to wear rapidly, due to the abrasion of the sand. A method adopted to reduce this wear is to chromium-plate these parts, and this has proved very effective.

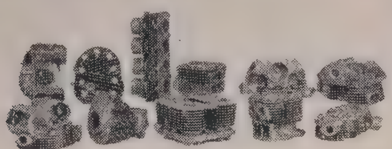
FIG. 1.—GROUP OF TYPICAL CASTINGS.

Coreboxes

Cast iron is used as often as possible, the extra cost of finishing being more than compensated by reduced wear. Constant sleeking off, even in this material, causes the faces of the boxes to wear hollow. A point which may be of interest is that cast-iron coreboxes have been recovered by welding along the face with low-carbon steel, and then grinding to finished size. This seems to be much more effective than using hardened steel plates, which have to be used on aluminium coreboxes. No trouble has been experienced from distortion, and this, it is thought, is due to the use of a high-duty cast iron containing nickel and molybdenum, which has a Brinell hardness of 270. The patternmakers express the opinion, however, that it works up just as well as ordinary cast iron, except that it is a little tougher.

Moulding Boxes and Core Plates

The necessity for using boxes that are rigid and accurate, and core plates that remain flat, is obvious. The larger proportion of the castings have to be cast vertically, and boxes must be bolted or clamped tightly into position before putting down for casting. All boxes are interchangeable, but due to pouring holes (used sometimes for special jobs) being cut on the long side, boxes that are fixed by clamps have to be made with a double set, and clamped on opposite corners instead of in the middle. Every time a box is stoved, an oxide skin forms, and in a surprisingly short time it becomes useless; steel boxes seem worse than cast iron in this respect, and although galvanised boxes are in use with satisfactory results, trouble is experienced after a while, with the fins fitting loosely. Boxes rebushed with stainless iron over five years ago have not worn at all. Boxes made up specially with heavy-section high-carbon steel, weighing nearly as much as cast iron of the same size, become distorted after a time, due to rough usage, and in view of the cost entailed in resetting at intervals, it is probable that a well designed alloy cast-iron box is the answer. At least it is known that boxes, once having passed on the jig, are true to size, until some heavy-handed individual distorts them.

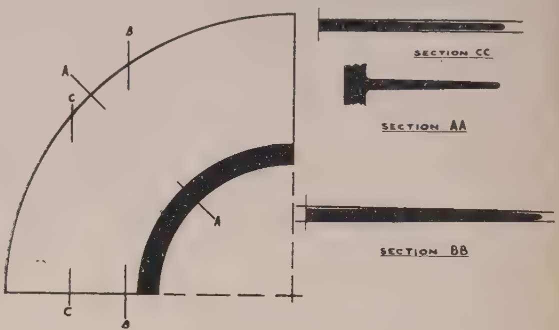

FIG. 2.—SHOWING FIN SECTION.

Sand

The basis of all sand used is Congleton silica sand. This is a similar sand to Southport, but contains a small amount of clay. The mechanical analysis given

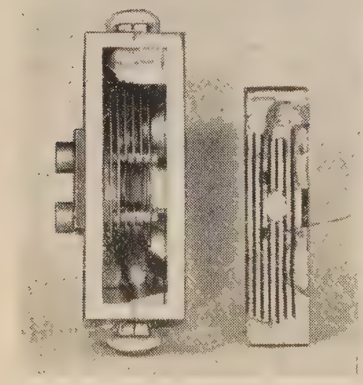
FIG. 3.—STRIPPING PLATE COREBOX ASSEMBLED WITH SAND CORE.

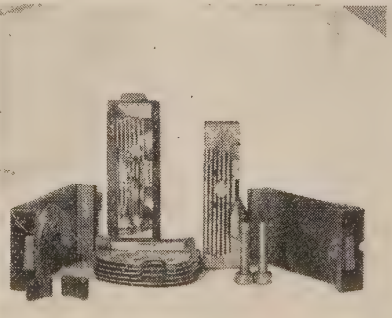
FIG. 4.—STRIPPING PLATE COREBOX DISMANTLED AFTER CORE IS MADE.

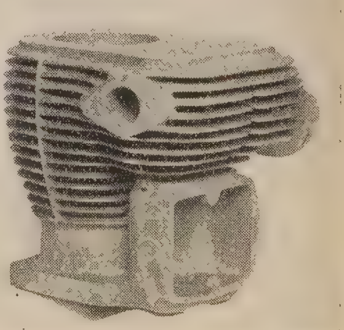
FIG. 5.—SIDE VALVE CYLINDER CASTING.

on Table I shows that the main sizes are spread over four sieves. This, together with the fact that a larger percentage of fines are present, gives a sand with good moulding properties, and a less harsh feel than that of Southport. Another important factor is that the chemical analysis shows an almost pure silica sand, which is of importance if sand recovery by burning is contemplated at any future date. Oil sand is used for the facing of all dried moulds, the mixture being made up of 60 per cent. recovered black sand, 40 per cent. new sand, and lightly milled to give a medium green bond. The same mixture milled for a longer period is used for making plain body cores and barrel cores.

Finned cores, and any cores which have to be packed, are made in new sand. All mixtures contain 0.75 per cent. dextrine, 0.75 per cent. linseed and 0.25 per cent. water. The physical properties of this sand are shown in Table II. The sand is mixed in Pneulec 6-ft. mills, of 672 lbs. capacity, and 500-lb. batches are used for oil sand. This, it is thought, helps to give an intimate mixture, which is necessary in view of the small amount of dextrine and linseed used. The new sand and medium black sand is milled for 4 min., and the stronger green bond black sand for 6 min. The sand is completely free from any stickiness during working.

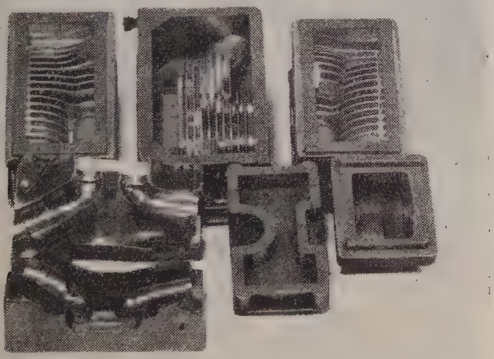

FIG. 6.—SET OF COREBOXES USED IN PRODUCTION OF SIDE VALVE CASTING.

All patterns and coreboxes develop an extremely high polish, and are very seldom cleaned. This is an essential feature when making finned work of this type. On our air-cooled cylinder production, a scrap casting from blowing trouble is a rare sight. The skin-drying properties of the mix are invaluable, as cores and moulds form a hard surface in a very short time, and assist the fins of sand to retain their shape while being taken to the stove, and, further, hold their shape until dried. Moulds and cores are dried in Acme vertical continuous stoves. Small and medium cores are dried for 1 hr. 10 min. at 550 deg. F. (285 deg. C.); and large cores and small moulds for 1 hr. 25 min. at 550 deg. F. Large moulds are dried on an automatic loader and unloader type stove for 1 hr. 35 min., at 600 deg. F. (315 deg. C.).

All moulds—and some cores—are sprayed with blacking while green. During the early days, when experimenting with recovered and new sand, the green bond developed without any further addition of dextrine was apparently sufficient for moulding, but a great deal of trouble was encountered with bad lifts. The explanation may be that the most important function of dextrine is that of providing plasticity rather than green bond. A special technique has to be employed for mixing the sand. To keep the green bond on the low side, oil and dextrine are put in first, and when thoroughly mixed the water is added, and before the sand gets too tough the mill is emptied. Sand of the correct flowability is obtained in this manner. No matter how skilled the operator, a closely packed mould cannot be made if the sand is too tough.

TABLE I.—*Mechanical Analysis of Congleton Sand, Together with Southport Sand for Comparison.*

	Congleton.	Southport.
	Per cent.	Per cent.
+ 22 mesh	0.5	Nil
+ 30 ,, ...	2.2	Nil
+ 44 ,, ...	9.7	Nil
+ 60 ,, ...	38.0	9.5
+100 ,, ...	40.1	76.3
+150 ,, ...	7.5	13.9
+200 ,, ...	1.1	0.2
−200 ,, ...	0.6	Nil
Clay	0.3	0.1

These terms are used, of course, only relative to the particular sand under review; a similar flowability is obtained with a natural bonded sand of 15 lbs. green bond, and, to digress further, the black sand used for making green-sand work is useless if above 7 lbs. green bond, should a good surface finish be required on the castings. A *true* flowability test which would indicate these differences would be invaluable. No apology is made for stressing the sand question, and instead it is stressed that the successful production of these castings depends on getting the sand correct, and keeping it so. To do this, it is preferable to check the sand by regular control tests, as in the author's case, due to the small margin of safety, production depends on all mixtures being correct. A general impression seems to be that

TABLE II.—*Physical Properties of the Sands Used.* (Laboratory Dried and Tested.)

	Standard Sand Mixture.			Backing Sand.
	0·75 dextrine, 0·75 linseed, 0·25 water.			0·65 Bondol, 1¼ per cent. Fulbond, 3 per cent. water.
	New sand.	60 per cent. blk., 40 per cent. new, milled 3 mins.	60 per cent. blk., 40 per cent. new, milled 6 mins.	
Green permeability ..	123	108	101	73
Green compression, lb. per sq. inch ..	0.25	1.6	3.1	8.8
Dry tensile, lb. per sq. inch, 1 hr. 450° F.	321	152	180	10
Dry tensile, lb. per sq. inch, 1½ hrs. 450° F.	348	122	162	10
Dry compression, 1 hr. 450° F.	—	—	—	80

synthetic sand is difficult to control, and as moulders do not take too kindly to its use, many people will not take the plunge and introduce it, on the assumption that it is necessary to make a big change-over.

Change-over to Synthetic Sands

A short account of how the change was effected in this foundry will, probably, dispel this idea. Eight years ago the backing sand was very close with a permeability of 30; drying trouble, already acute, was becoming worse. About this time a Paper[2] by J. J. Sheehan had been published, and from the information given, it was thought that some benefit might be gained by using a more open sand. The knock-out sand from the castings made with oil-sand facing was recovered, bonded with clay, and used as backing sand. A permeability of 100 was obtained in this manner, and was found to halve the drying time. The larger proportion of castings was still being made in red sand, and, unless strict supervision was kept, a certain amount of burnt red sand got into the new backing sand and reduced the permeability to about 50.

Special care in keeping the two types of sand apart had the effect of restoring the open sand to its original condition a little time later. No further troubles cropped up for some months, but although the different sands used were being kept separate, sand tests showed the permeability figure slowly, but surely, getting lower. One or two friends ascribed the trouble to silt. The author could not accept this view, as he had sufficient faith in the early experiments to disregard this theory. The trouble was eventually traced to the runner bushes, which were being made in the naturally bonded black sand. It seems fairly obvious now that this could cause trouble, but at the time the relatively small amounts going in were not thought to be capable of exerting such an influence. The cure was for the whole of the bushes to be made in synthetic sand.

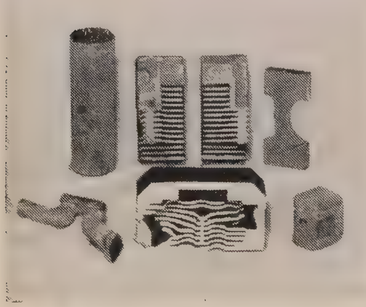

FIG. 7.—SET OF CORES MADE FROM EQUIPMENT SHOWN IN FIG. 6.

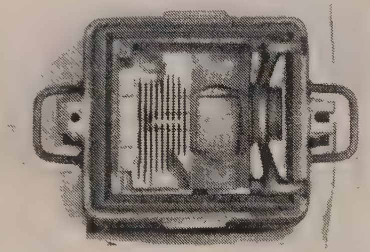

FIG. 8.—BOTTOM PART OF MOULD.

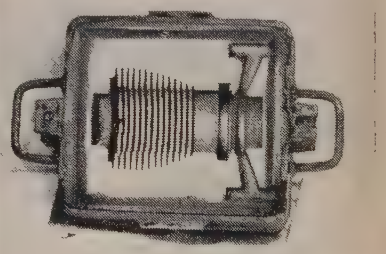

FIG. 9.—TOP PART OF MOULD.

At that time a heavy type pug mill was being used for preparing the naturally bonded facing sand, and, with a mixture of six shovels of red and eight of black, the milling time required to turn out the sand in condition for moulding was 15 to 20 min. The mixture was altered to 1½ shovels of red, 3 per cent. clay, and the balance black; it was milled 6 to 7 min. At one time the foundry received no new red sand for four days, and no complaint was made until one of the moulders noticed the absence of red sand. This led to an immediate outburst to the effect that the sand was useless without some red sand. A week later, for some days all red sand was left out, but red dye was added which gave the appearance of having more red sand than usual, and the only comments made were favourable.

Relative Advantages and Disadvantages

The reduction of red sand in the facing meant that the backing sand had to be made up with knock-out sand, which included a good proportion of burnt sea sand, but, although quite large quantities were put in, very little improvement showed in the permeability for nearly twelve months, when the figure reached was 35. The final change was then made by holding back a quantity of oil-sand facing from the knock-out (a certain amount of which always has to be carried away), dumping half the naturally bonded sand and replacing it with knock-out sand, and the foundry was put on a synthetic basis. In two or three weeks the sands were sufficiently mixed to show on tests that the permeability was between 75 and 80. Amongst the points to be made against the use of a synthetic sand is the somewhat rapid drying-off property, due to a rather narrow moisture range, which is especially noticeable if the sand be hot. It must be milled if a good green bond and permeability are required, with a minimum amount of clay, and more plant is required than is usually necessary when using naturally bonded sands. However, assuming that the plant is available and efficient, the only really serious problem is drying off.

In favour of synthetic sand, the following points do, in personal opinion, more than offset the disadvantages. Sand properties are uniformly and closely controlled, less skill required in ramming up moulds, much faster drying rate, due to more open sand, reduced amount of rough fettling, not only because there are many less pins to remove, but the sand is more refractory, does not burn on, and shortens shot-blasting time. Having one sand as a base, all batches can be put through the same mills without cleaning out. Air-cooled castings have to be cast quickly, and naturally there is a big strain on the fins of sand in the mould. A casting can easily be scrapped due to indifferent pouring, and the present methods used show a greater margin of safety. The fact that, apart from drying troubles, the foundry does not see a swelled casting for months at a time, is ample proof to the author that a permeable mould is essential. Scrap up to 5 per cent. from this cause was not considered too bad at one time with close sand. Very few pins are needed to support the fins, and then usually only while the sand is green. In one job, for example, previously 160 pins were used, whereas now about 14 are required. Mould production is much more rapid, and a clean lift is guaranteed owing to the addition of 0.75 per cent. dextrine.

Metal Composition

The analysis shown in Table III is only varied when castings are required for high-pressure work, in which case the phosphorus is reduced to 0.20 per cent. No steel is used in the mixture, mainly because of the difficulties of obtaining a thoroughly homogeneous mixture under existing operating conditions. Castings made in 0.6 phosphorus all show a network of phosphide with a mixture of pearlite and ferrite. The Brinell hardness runs from 210 to 230, usually taken on the holding-down flange. Metal charges normally consist of three brands of pig-iron, two of which are refined iron, and one a straight blast-furnace iron. This is enough to give a good mix, and should any trouble arise, it is fairly easy, by process of elimination, to find out at any time which iron is giving trouble.

TABLE III.—*Standard Analysis.*

Total carbon	3.20
Combined carbon	0.70
Silicon	1.95
Phosphorus	0.60
Manganese	0.75

Whilst not normally having a conservative outlook, this is one item that has to be carefully considered when making a change. It is felt that certain irons have hereditary properties that cannot be explained by analysis. Iron is purchased by analysis and fracture. The straight iron is never used in a proportion greater than 25 per cent., and if this figure be exceeded, open grain and porosity are likely to be experienced in heavy sections. While making high-duty cast iron, in which up to 25 per cent. steel is used, it was decided to see the effect steel had on ordinary mixtures. These were made up for a period of three months, varying the steel content from 12½ to 25 per cent., and keeping the final analysis the same. It seemed that the straight iron could be increased to 33⅓, with 12½ per cent. steel, and still keep heavy sections sound. Sections of castings are extremely varied; it is now quite common to have thin walls of $\frac{5}{32}$ in. thickness, which have to be machined, not ground, running on to heavy sections of ¾ in., and in this latter portion due to the design, the rate of cooling is often very much retarded. Over five years have elapsed since the foundry has had a casting returned for porosity (no pressure testing equipment is available at the foundry), and during this period no serious complaint has been received about machinability.

Cupolas

Two cupolas are lined to 24 in., to a height of 2 ft. 9 in. above the tuyeres, and then flared to 33 in. in the preheating zone. Four tuyeres are used, 5½in. by 4½ in., giving a ratio of approximately 4¾ to 1. Volume and pressure gauges of Metronic Instrument Company's make are used on both cupolas. Distribution of the air in the cupola is important and continual checks are taken to ensure that an equal volume of air is passed through each tuyere. In this particular case it is very essential, as the lining in the preheating zone is only 3 in. thick, and after only melting about 80 tons, *i.e.,* three weeks' use, 1 to 1½ in. is left at this point. The wear at the superheating zone is regular, and no trouble arises due to localised erosion.

The first blow with a newly prepared lining, on one occasion gave uneven wear at a point just above the tuyeres. This was found to be due to one of the tuyeres being offset about 7½ degrees. Investigation showed that this restricted the air delivered at this tuyere by about 15 per cent. Cases have been known where the tuyères appeared evenly balanced according to the indication of the control valves, and yet in actual fact showed a variation between the highest and lowest reading of 80 per cent. in the volume of air delivered by each.

The lining is prepared with a proprietary monolithic refractory material, which is rammed round a plug once every 14 days. This is the only material so far found to withstand the temperature in the superheating zone. Silica bricks, high alumina bricks, all melt away about 1 ft. to 2 ft. above the tuyeres.

Normal practice is followed in the preparation of the lining and in repairs. The inside is patched the day before the cupola is used, the hot walls help to dry the patching material and a small fire is put in the bottom to complete the drying. Preparing the day before helps to get an early start, this is especially important during the winter months, as the cupolas are not blacked out. After burning up during the morning, the back plate is made up when the fire has burnt up to a height of not more than 12 in. above the tuyeres. The bed is then made up to 42 in. with 5-in. coke, and as soon as the cupola is charged, the blast is put on. If the bed does get thoroughly burnt through, dull metal is obtained, whereas following the above pratice, intricate castings can be poured after about 1¼ cwt. has been run through. Nine 4-cwt. charges, consisting of 3 cwt. pig, 1 cwt. own runner scrap, with 60 lbs. coke, and 14 lbs. limestone, are charged to fill the cupola, and this is about one hour's melt. The fan is run to give 1,100 ft. per min. at 8½ ft. w.g. for the first 30 mins., then reduced to 850 ft. per min. at 6 in. w.g., and left at this position for the remainder of the cast.

Melting Conditions

A melting rate of about 35 cwts. an hour is maintained; this seems to be an optimum condition, and if increased to 2 tons an hour, scrap castings through misrunning (although the temperature seems sufficiently high), and gasholes appear. This latter trouble used to occur at one time when using a particular refined iron, which had been produced under conditions of high melting rate.

The essential factor to control is the amount of coke used per hour. Although a rate of melting of 35 cwts. per hour may at first sight appear low, it must be noted that the metal to charge coke ratio is 7.5 to 1. With a similar rate of coke burning and a ratio of 10 to 1, this corresponds to a melting rate of 50 cwts. per hour. To obtain 2 tons per hour with a 7.5 to 1 ratio corresponds with an output of 55 cwts. at a 10 to 1 ratio. Such an output from a 24-in. bore cupola could, in personal opinion, only be obtained by overblowing. The amount of air consumed is low, and suggests, according to published data, that the thermal efficiency is low, nevertheless, metal troubles are very small, and the foundry is melting iron at consistently high temperatures.

One casting (Fig. 5) only has been taken as an example to avoid confusing the issue, with one exception, that a core made from the stripping plate corebox, mentioned previously, is shown. This casting was chosen partly because it really incorporates three methods of production. The top part, as shown in Fig. 9, is moulded in the ordinary way. The middle part is cored out in the normal manner, and the bottom part, as shown on Fig. 8, is made by ramming up the core with the mould. This has to be done to ensure that this front block core is placed correctly, as the valve core is set into this core, and a further core rests on the front portion of this block core. The weight of these moulds ready for casting is 135 lbs., and it is possible to produce 120 castings in an 8-hr. day.

Foundry scrap from all causes amounts to 3.5 per cent., and quite a large proportion of this scrap figure is due to breakages. Return scrap after machining is 1.2 per cent. These figures are taken over the last twelve months. It might appear that some of the operations (illustrated in a film which the author exhibited) are speeded up, but it can be asserted that the movements are as seen, in actual practice. The certainty of obtaining a good lift gives confidence, and a speed of working that would not be reached otherwise. The two cores for the middle portion are made in less than 2½ mins. The usual practice followed takes at least 20 mins. to make the same core. These cores are jigged, and then gauged into the mould. The author deems it to be better in the ordinary way to make the cores with no allowance for jigging, but this is an exceptional case. Casting with a 450-lb. ladle ensures a uniform metal composition, and the drum type ladle holds the temperature longer than the open type.

All fettling and final dressing must be done by hand, and it is fairly obvious if the shape of the casting is taken into consideration.

To conclude the author would like to thank Mr. W. Jackson, of the Idoson Motor Cylinder Co., Ltd., for permission to present this Paper, and the British Cast Iron Research Association, particularly to Mr. L. W. Bolton and Mr. W. B. Parkes for their kindly interest and constructive criticism.

DISCUSSION

In opening the discussion, MR. A. G. HARRISON proposed a hearty vote of thanks to Mr. Taft, assuring him that they fully appreciated the value of the slides and the films exhibited. The firm were evidently accomplishing a good job of work, as they were keeping their scrap down to such excellent figures.

MR. F. J. COOK, in seconding the motion, remarked that it had often been said in the past they did not get enough practical Papers. He thought Mr. Taft's Paper would satisfy everybody from the practical point of view. He congratulated the author on a series of excellent slides of a difficult subject and also for incorporating a great deal of information in his Paper. If it was published he believed it would be a standard work on the making of those particular cylinders. Looking back he could not find any information regarding that class of work either in the records of the American Foundrymen's Association or those of the Institute. He was convinced that the Paper would fill a long felt want.

MR. TAFT then interposed, and asked members if they could help him solve a problem. One interesting snag facing any engineer in designing an engine was to keep it mechanically quiet, and he had carried out a large number of experiments with a view to reducing the tendency of such cylinders towards resonance. However, he felt he was just groping in the dark, and if anyone could give him a lead he would be glad.

MR. J. J. SHEEHAN said he had no criticism to offer, and he thanked Mr. Taft for his references to himself. He did not think it would be possible to reduce the percentage of oil and dextrine used, and the same was true of the proportion of synthetic sand.

Replying, MR. TAFT said he knew the percentage of synthetic sand was low, but they were rather fussy in regard to mixing, realising that if they went about it in a haphazard manner they would encounter trouble. Although Mr. Sheehan did not think they could reduce the oil and dextrine further, he had been trying to get it down to limit drying time on some particularly heavy jobs. They were not really dry, and, owing to lack of drying, oil was left in the cores. For ordinary purposes it was difficult to cut it down any more.

Resonance and Mechanical Noise

On the question of resonance, MR. SHEEHAN pointed out that an efficient air-cooled engine was bound to produce a certain amount of noise, and springs, etc., amplified the already existing mechanical noises.

MR. TAFT said they were trying to get the least resonance and to cut down the mechanical noise. They found aluminium much worse than cast iron. They believed it could be overcome, but the moulding problems associated with it were extremely difficult.

Replying to questions by other members, MR. TAFT explained that his firm's experience had been that to turn the casting up to pour was the safest way. If cast in the moulded position, the metal did not run clean. Unless it was cast from the centre the structure would be different and the stresses due to different temperatures in the mould would be considerable. He was referring in general to rather intricate types of cylinders. With regard to welding coreboxes he did not know what happened when low-carbon steel was welded on to cast iron, but he presumed it became high-carbon steel. It was intensely hard, and thousands of castings could be made before it was necessary to go through the process again.

MR. A. TIPPER wondered whether core blowing would not enable them to cut out some of the pins.

MR. TAFT, however, pointed out that pins were only put in to hold the fins in the green state, and core-blowing would not get rid of any of them. Asked by Mr. L. W. Bolton if he thought the long fins were really necessary, MR. TAFT said it had been definitely proved that they were not efficient beyond a certain point and were put on for ornament. Most of them were too long to be efficient. In general, if the fins were designed to give the maximum thermal efficiency, much less trouble would arise from resonance.

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Metallurgical Factors of Importance to the Practical Aluminium Founder

By S. A. E. WELLS*

[In presenting this Paper the author included some information (particularly on the contamination of aluminium by iron, the effect of melting temperature, and grain refining) previously published in a Paper, "The Effect of Melting Conditions on Light Alloys," by A. J. Murphy, R. J. M. Payne and himself.† Such information has not been included in the following.]

Contamination

In connection with the contamination of aluminium by iron, the following experiment will be of interest: A piece of cast iron freshly filed on all surfaces was dropped into a crucible containing some molten aluminium at a temperature of 750 deg. C. The crucible was then removed from the furnace and the contents allowed to solidify. When cold the resultant block of metal was suitably prepared for microscopic examination. Fig. 1 shows the result.

Another form of contamination which should be mentioned is the inclusion of oxides in the molten metal. These inclusions usually arise from the oxide scum covering the metal being pushed under the surface either when making additions to the charge or during stirring. Elementary precautions will prevent this happening. Additions to the melt should only be made after the oxide scum on the surface has been pulled to one side to expose clean metal, and when stirring is contemplated the surface should be skimmed clean beforehand. It is, however, desirable to limit the amount of stirring to avoid disturbing the oxide scum unduly because the film provides a cover which arrests further oxidation and therefore cuts down metal losses.

It is much better to take steps to avoid the entry of oxides into the metal than to have to remove them subsequently. The oxides being somewhat similar in density to the metal itself, do not separate easily by reason of differences in density as is the case with some metals, and once they become entrained they are difficult to remove and one must resort to flux treatment. The latter, however, is not always completely effective. There are, of course, other reasons for the appearance of oxide inclusions in castings, such as turbulent pouring, etc., but one should at least do what one can to ensure starting off with reasonably clean metal.

Grain Refining of Ingots

In the production of ingots for forging an intrinsically fine-uniform grain size in the ingot or billet is of primary importance, and unless this is obtained, consistent progress in the mechanical working operations cannot be expected. Material possessing a coarse non-uniform grain size appears to be inherently weak at the working temperature and is liable to crack under the shock of hammer blows.

In respect of large forgings fabricated from ingots or billets, there is another reason which makes a fine grain size in the original cast ingot especially desirable. The production of large forgings is usually accomplished under conditions of some limitation. There is frequently a restriction on the size of the ingot that can be used, and thus the reduction of section that can be achieved under the hammer or press is insufficient to produce optimum mechanical properties. In these circumstances the finer the grain size of the original ingot the better are the mechanical characteristics, notably the ultimate stress and elongation in the tensile test, of the material in the finished product.

There is an important reason why 800 deg. C. is adopted as the pouring temperature for the grain size test. It was considered that unless the grain refiner would exert its full effect on metal that had reached a temperature of 800 deg. C., it could not be expected to take care of the extremes likely to be encountered in practice. Experience has established that this reasoning was correct.

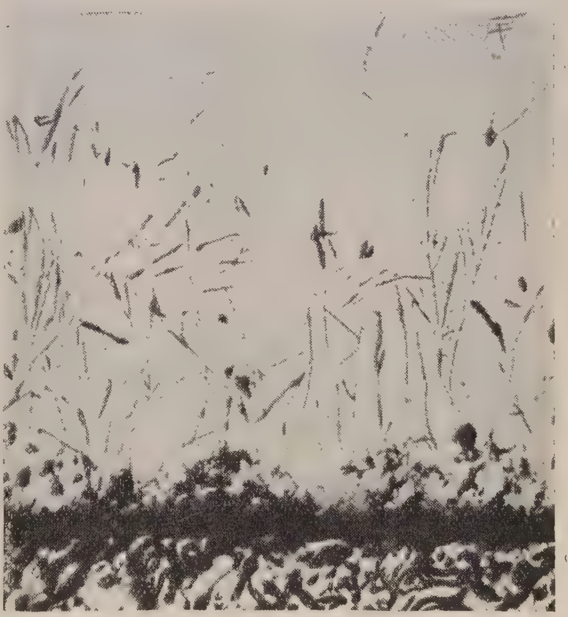

FIG. 1.—ILLUSTRATING THE AFFINITY OF ALUMINIUM FOR IRON. THE NEEDLES OF THE IRON-ALUMINIUM COMPONENT FORMED IN THE REGION OF THE INTERFACE CAN BE CLEARLY SEEN. (x 150).

In any investigation relating to the grain size of aluminium alloys it is necessary to be aware of the spurious effects which can be introduced by the presence of dissolved gas. The escape of gas from the cooling metal as it approaches the freezing point and during solidification causes agitation, which in itself produces a certain small degree of grain refinement. It is therefore desirable to eliminate this factor, by ensuring that the molten metal is substantially free from dissolved gas when testing grain size, and the use of a suitable degassing flux is recommended.

Generally speaking, the amount of the grain refining element to be added is quite small; in fact, less than

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* Metallurgist, J. Stone & Company, Limited.

† Proc. I.B.F., Vol. XXXII, 1938–39, pp. 133–140.

0.2 per cent. is required. When using niobium or titanium, the grain refiner is conveniently added in the form of a hardener or key alloy, the bulk of which consists of aluminium.

It is desirable to use a moderately dilute hardener containing about 5 per cent. of the refining element, as this makes for easier working and avoids having to raise the alloy proper to the high temperature which would be necessary to dissolve a richer hardener. When alloys sensitive to iron "pick-up" are to be grain-refined it is self-evident that the iron content of the hardener must be controlled and kept as low as possible, in order that when an addition of the grain refiner is made, the iron is not increased beyond an amount that can be tolerated.

Influence of Titanium on Grain Refining

Turning to consideration of titanium, this element is capable of grain refining a similar range of alloys to those in which niobium has been found to be effective. The amount of titanium necessary to ensure a consistent grain size of a fine order appears to be about 0.15 per cent.

This was confirmed as the result of examining an inconsistency in behaviour of a straight 4.5 per cent. copper-aluminium alloy grain refined by means of 0.10 per cent. titanium, in which the refining action did not seem to be reliable. As a good deal of the material concerned had been subjected to several remeltings without flux, it was thought that possibly a loss of titanium may have resulted from repeated remelting.

Some of the ingot was taken and remelted five times, reaching a temperature of 800 deg. C. at each remelting. The titanium was then estimated in samples from the first, third and fifth remelt, and compared with the titanium content in the original ingot. The chemical analysis figures were:—Original ingot, 0.095 per cent. Ti; 1st remelt, 0.097 per cent. Ti; 3rd remelt, 0.098 per cent. Ti; 5th remelt, 0.094 per cent. Ti; and these led to the conclusion that no loss of titanium is to be anticipated on repeated remelting.

The trouble with this material was eventually eliminated by adding a further 0.05 per cent. titanium, thus indicating that the initial titanium content was insufficient, as is shown in Fig. 2.

It is inadvisable to add excess of the grain refiner over the amount necessary to obtain optimum effects, because there is a tendency for loss of elongation with increasing quantity of the refiner, for example over 0.3 per cent. of either niobium or titanium is detrimental. Of other methods of introducing the grain refining element into aluminium alloys, perhaps the best known is that of treatment with special fluxes. In this case the flux carries the refining element in the form of a salt. When the flux is plunged into the molten alloy it is decomposed, with the result that the grain refiner is released and enters into the metal. Boron, which has been mentioned as one of the outstanding grain refiners, is usually added in this way with good effect.

The theoretical side of the question of grain refinement is very involved, and needs a good deal more work to elucidate the mechanism before an entirely satisfactory explanation is likely to be forthcoming. An interesting theory is that the grain refining constituent, which invariably has a higher melting point than the basic alloy, is thrown out of solution as a shower of sub-microscopic particles as cooling proceeds; these particles then act as centres of crystallisation over and above those normally provided by the solidification of the alloy itself. On the number of nuclei thus available depends the final grain size of the metal; broadly speaking, the greater the number within limits the smaller will be the grain size.

Although this may not be the complete story, the

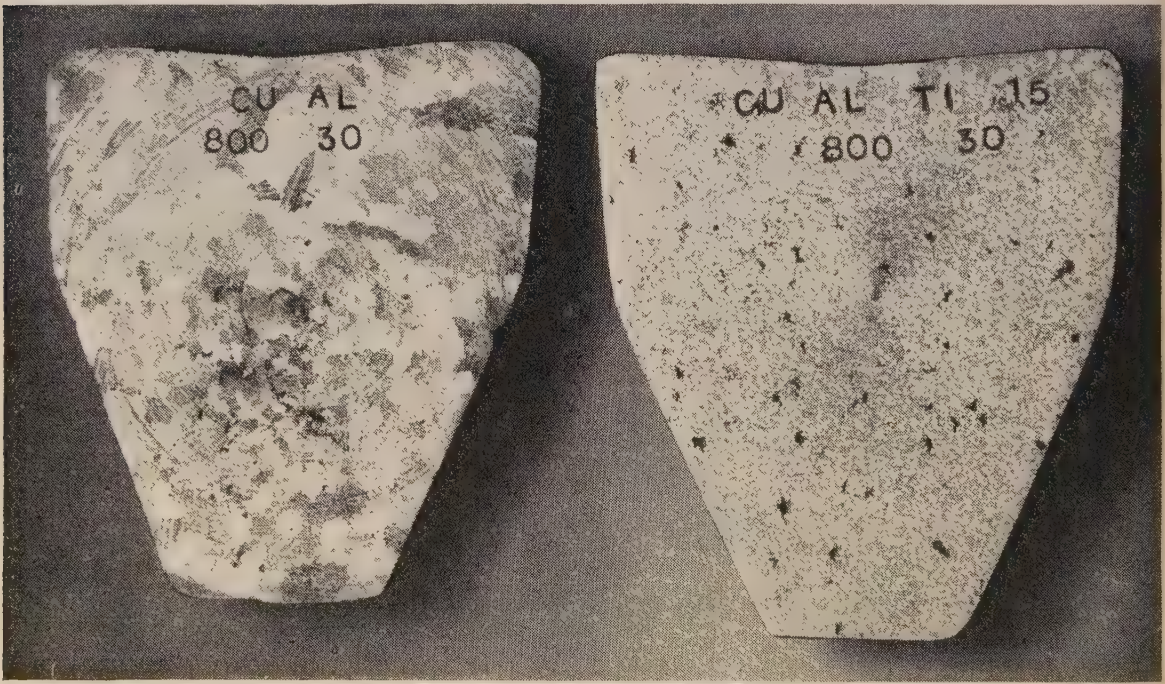


FIG. 2.— 4.5 PER CENT. COPPER ALUMINIUM ALLOY. UNREFINED ON LEFT; REFINED WITH 0.18 PER CENT. TI ON RIGHT.

fact that segregation of the grain refining constituent occurs when the metal is held for a period in the tranquil state at a low temperature, certainly indicates that something of the sort does happen.

The remedy for ensuring freedom from this type of segregation is to give particular attention to stirring immediately before transferring the molten metal from the melting furnace or pouring castings from a crucible. This is shown in Figs. 3 and 4. It can be seen from the foregoing observations on grain refinement that, when using an aluminium alloy which is intrinsically fine-grained, on account of the presence of a special element, the founder is relieved of one serious restriction in melting conditions, namely, the necessity for maintaining the temperature of the melt below the critical level above which grain coarsening occurs. This is not to say that the other advantages of low melting temperatures, such as decreased gas absorption, do not remain, but a greater latitude in working conditions is certainly permitted.

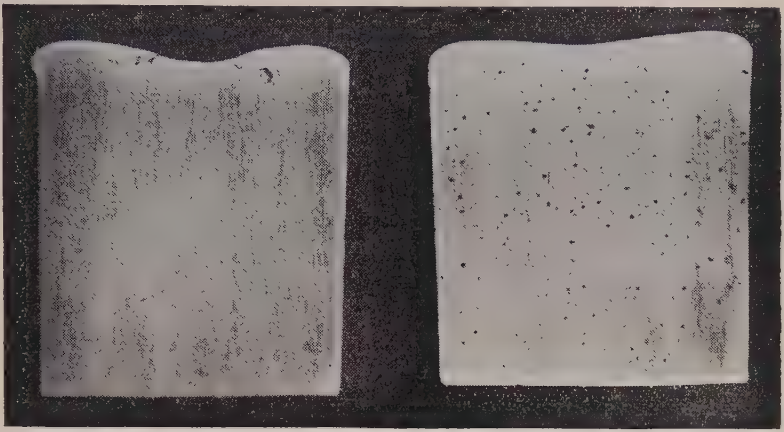
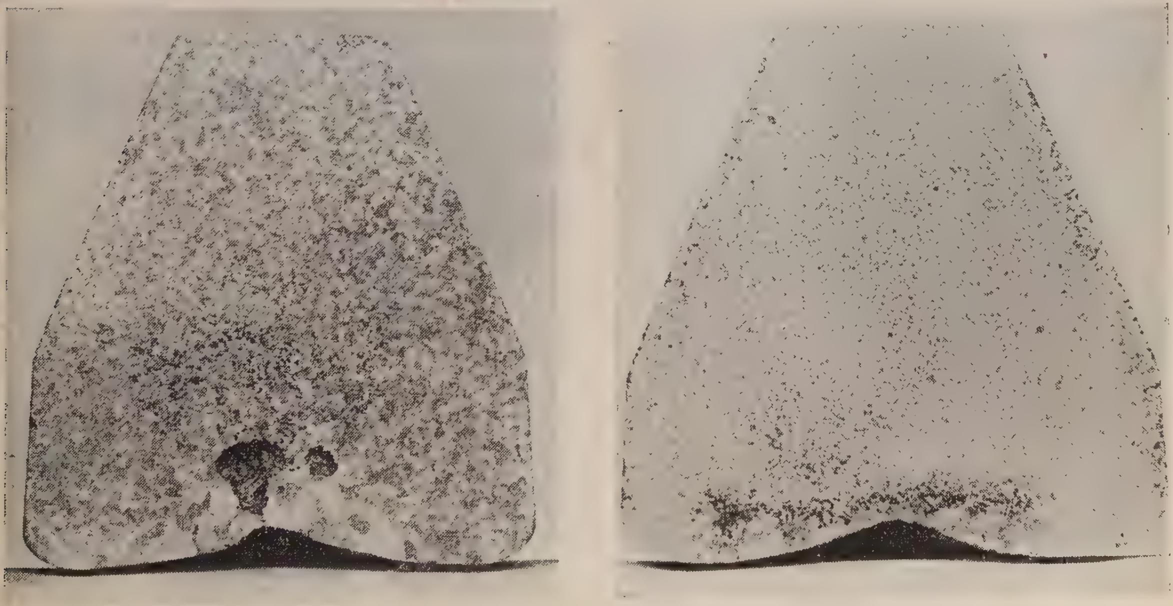

TREATED. UNTREATED.

FIG. 5

Gases—Occurrence, Causes and Removal

Founders of aluminium alloys are familiar with the troublesome defect known as "pinholing" or speckling in castings. These "pinholes" or "speckles" consist of small cavities which vary in shape according to the crystallisation characteristics of the alloy, and become visible when the casting is machined; they are usually disseminated through the body of the casting and therefore persist irrespective of the amount of metal removed in machining. Sand castings are prone to exhibit the trouble to a marked extent, but die-castings seldom show the defect.

Dissolved gas in the metal is the generally accepted cause of the "pinholes," and it is mainly attributed to the absorption of hydrogen by the melt. In the majority of cases water vapour is the source of the gas. The water vapour is decomposed by the molten aluminium and sets free hydrogen, which is immediately absorbed by the metal. Particularly harmful is the presence of water vapour in the furnace atmosphere; this can arise from the air supplied for com-


TOP OF MELT. BOTTOM OF MELT.

FIGS. 3 AND 4.—ILLUSTRATING THE EFFECT OF SEGREGATION OF THE GRAIN REFINER ON GRAIN SIZE, IN A MELT HELD IN THE TRANQUIL STATE FOR 1 HOUR AT 700 DEG. C. THE BOTTOM PORTION OF THE MELT IS ENRICHED AT THE EXPENSE OF THE TOP PORTION, WITH THE RESULT THAT THE TOP AND BOTTOM EXHIBIT DIFFERENT GRAIN SIZES. REFINER: 0.10 PER CENT. NIOBIUM.

bustion, from the fuel itself and not infrequently from residual moisture in the furnace lining or crucible. It is an established fact that newly lined furnaces often yield gassed metal for a while, even when dried out and heated to redness before use. Damp coke in pit fire furnaces is a very potent source of water vapour and emphasises the importance of storing the fuel under cover. In fact, to ensure freedom from gas "pick-up" from the coke, it should be completely dried before use.

Corroded metal is another means by which gassing of a melt can take place; in this case the salts formed as products of corrosion produce water vapour when the metal is heated; the danger can, of course, be minimised by removing the corrosion by such means as shot blasting, scratch brushing, etc., before melting. The offending gas can also be introduced into a melt by the metals constituting the charge. In this event the metals themselves are gassy and carry the hydrogen into the melt to which they are added. Other gases in the furnace atmosphere do not readily diffuse into aluminium and its alloys at the usual melting temperatures, and little trouble is likely to arise from these gases under ordinary circumstances.

Elimination of Pinholes

The question of eliminating "pinholes" by the removal of the gas from the melt has received attention for some years, and methods have been evolved by several investigators all of which are capable of effecting improvement. Objections have been raised to the employment of most of the methods on the ground that there is either an uneconomic time factor involved in the process or somewhat elaborate apparatus is necessary. In more recent times the employment of fluxes has been developed with pronounced success, and the simplicity of application of these flux treatments has resulted in the older methods being largely superseded.

In some cases the flux is thrown on to the surface of the molten metal and stirred in, the stirring being repeated several times during cooling, while with other fluxes a special plunger is used to carry the flux to the bottom of the crucible and hold it there until action ceases. Most of these fluxes consist of mixtures of two or more chlorides and fluorides of the metals sodium, potassium and lithium. It is, of course, essential that these salts mixtures are perfectly dry when used so as to exclude the possibility of the presence of water vapour, whose damaging effect was examined earlier. A typical example of these fluxes is a mixture of two parts by weight of sodium chloride and one part by weight of sodium fluoride, the commercial quality of the salt being used in each case.

The procedure in using the flux is to raise the metal temperature to 750 deg. C. and then an amount of flux equal to 0.5 per cent. of the weight of metal is spread evenly on the top of the metal and the flux pushed under the surface by means of an iron skimmer, until the flux rising to the top again is seen to be fused. The metal is then stirred several times, after which the products of the treatment are skimmed off, and the metal cooled to casting temperature. If for any reason it is desired to measure the temperature of the metal while the surface is covered with flux, a steel-sheathed pyrometer should be used or the readings may be unreliable.

The effectiveness of the method described is illustrated in Fig. 5, which shows sections of 3 in. dia. blocks cast from the same melt, before and after treatment. The metal is Ceralumin "B" to specification D.T.D. 287. It is not advocated that degassing treatment should be employed as a matter of routine, but only when it appears to be necessary. Three reasons can be cited for exercising discretion in this direction: (1) Crucibles made of siliceous materials are attacked to some extent by the fluxes, particularly those containing fluorides, which incidentally are the most effec-

TABLE I.—*Effect of Repeated Melting—"Alpax Gamma."*

	Magnesium per cent. by analysis.	"As Cast."	Heat-treated.			
		Brinell hardness, 10/1000/15.	Brinell hardness, 10/1000/15.	0.1 Per cent. Proof stress. Tons per sq. inch.	Ultimate stress. Tons per sq. inch.	Elongation. Per cent. on 2 inches.
Repeated fluxing—						
1st fluxing	0.33	60.5	120	— 16.50	17.88 19.00	1 1
2nd fluxing	0.20	60.5	112	— 16.40	18.60 18.80	1.5 1
3rd fluxing	0.19	58.3	106	— 15.08	18.00 18.48	2 2
4th fluxing	0.10	53.8	104	— 13.48	17.40 17.84	2 3
Repeated remelting without flux.						
Original melting ..	0.42	59.8	120	— 18.56	18.24 18.56	0.5 0.5
1st remelt	0.41	55.8	125.5	— —	17.76 18.28	Nil 0.5
2nd remelt	0.38	60.5	125	— —	17.44 17.40	0.5 0.5
3rd remelt	0.35	55.1	126	— —	16.90 17.00	1 0.5

tive degassers; (2) removal of gas from the metal increases shrinkage, and this necessitates greater attention to moulding technique to ensure adequate feeding of the castings; and (3) changes in chemical composition can occur as the result of flux treatment.

Fluxes which are manipulated by plunging into the melt are those that function as the result of the evolution of an active gas such as chlorine.

Change in Composition

In general, one does not have to contend with volatilisation in alloys of aluminium; there remains, however, the possibility of the composition of the charge being altered by the loss of one or more of the constituents during melting, and the investigations now to be described briefly show how a change of composition can occur in certain aluminium alloys.

The object of the experiments was to ascertain if any loss of magnesium occurred either when flux degasification treatment was applied to a melt or when the melt was subjected to ordinary melting only without fluxing. Alloys Ceralumin "B" (D.T.D. 287) and "Alpax Gamma" (D.T.D. 245), with nominal magnesium contents of 0.1 per cent. and 0.4 per cent. respectively, were chosen for the investigations, and the effect of repeated application of flux and the influence of remelting several times without flux were examined.

The fluxing experiments were carried out on single 20-lb. melts, which were treated four times with a dry flux mixture of 2 parts sodium chloride and 1 part sodium fluoride, using 2 per cent. by weight of the salts mixture on each occasion. At each stage the temperature of the metal was raised to 750 deg. C. for fluxing, and after fluxing cooled to 700 deg. C. to enable two standard test-bars to be poured. The heads of the test-bars were cut off and returned to the crucible to maintain an approximately constant area of surface of metal exposed to the action of the flux. The quantity of the metal treated therefore only varied by the small amount required for the test-bars.

The remelting experiments without flux were also made on single 20-lb. melts. The procedure was to raise the temperature of the melt to 750 deg. C., cool to 700 deg. C., and cast two standard test-bars and then pour off the remainder into ingot moulds, the ingots and the heads cut from the test-bars being remelted at each stage. Three stages of melting were carried out in all. Samples consisting of turnings from the complete cross-section at the top of a test-bar representative of each stage of the experiments were taken for determination of the magnesium content in both the fluxed and non-fluxed series. The normal heat-treatment for the respective alloys was applied to the test-bars before making mechanical tests. Brinell hardness determinations were also made on pieces in the "as cast" condition, as it was thought that some difference might be observed even at this stage if any marked loss of magnesium had occurred.

Loss of Magnesium

Considering the results of the experiments on Ceralumin "B" it is found that a serious loss of magnesium can occur from a repetition of the fluxing treatment, resulting in a softening of the alloy, the effect being marked on all the mechanical properties examined. The series of tests on the repeated remelting of the alloy in the absence of the flux show that no loss of magnesium need be anticipated. Tensile tests were not carried out in this series of experiments as it was obvious from the chemical analysis and hardness tests that no loss of magnesium had occurred.

Turning to the experiments on "Alpax Gamma," losses of magnesium are shown by Table I to be substantial in the metal subjected to repeated flux treatment, and it will be noticed that 75 per cent. of the original addition has been lost after the four treatments. A small loss has occurred on repeated remelting without flux. The test figures demonstrate that decreases in the magnesium content as the result of flux treatments of the melt materially influence the proof stress, ultimate stress, elongation and Brinell hardness. In the case of remelting without flux, where the loss of magnesium is much less, there is a tendency for the ultimate stress to decrease at the same time as the magnesium.

An interesting observation is that in spite of removal of magnesium all the test-pieces gave values of tensile strength in excess of the 15.5 tons per sq. in. required by specification D.T.D. 245. If for any reason a melt of aluminium alloy of the types examined is treated more than once, or at the most twice, with a flux of the kind described, an addition of magnesium should be made to compensate for the loss due to the action of the flux. The same consideration has to be borne in mind if remelted runners and risers that have previously received flux treatment constitute a large proportion of the charge, a condition which is likely to arise when the metal ratio on a job is high, that is when the weight of the untrimmed casting is large in relation to the finished casting.

Ceralumin "B" does not show a loss of magnesium when remelting in the absence of the flux in the same manner as "Alpax Gamma"; this is probably due to the much lower initial magnesium content of the material making it less prone to selective oxidation. Although the experiments described deal with the effects of one flux only, the case is not exceptional, and in searching for a reliable degassing flux, different mixtures have been tried, including many proprietary fluxes, but so far all have had the same effect on the magnesium content of the alloy or have failed to satisfy as degasers.

In conclusion, the author expresses his thanks to the directors of J. Stone & Company, Limited, for permission to use the results of the investigations reported in this Paper, and also to his colleague, Mr. J. P. Ellis, for his assistance in the preparation of the lantern slides.

DISCUSSION—LANCASHIRE BRANCH

Practice and Theory

MR. A. PHILLIPS inferred from the Paper that in melting aluminium alloys it was necessary, first of all, to take care of the gases and to avoid absorption of iron from the container, and then, when that had been done, when the metal was cast in the mould, it must not re-absorb gases from the mould. The problem of the removal of gases, especially hydrogen, from aluminium alloys was likely to be troublesome to founders for a long time to come.

In the early part of his Paper, Mr. Wells was very emphatic in stating that aluminium alloys should not be heated beyond a certain temperature. He differed somewhat from Mr. Wells' opinion in that respect, because nowadays it was not advisable to be dogmatic. At one period it was found that aluminium alloys of the silicon-aluminium type, when an addition of fluorides, etc., was made to the melt, underwent a change in physical condition. Along with others, the foundry with which he was associated had carried out experiments, and had discovered that, by adding the salts, and raising the temperature of the metal to 1,060 deg. C., then allowing the metal to cool down in the furnace, there was obtained an alloy which was of quite small grain size and free from gas. They had found that in many cases, where they had been told not to do a thing, that if they did it, the result proved to be satisfactory.

In some cases it was necessary to run very fine castings of aluminium, and to limit the temperature as Mr. Wells had suggested, but it was difficult to pour.

What was Mr. Wells' opinion concerning the gating of alloys, because it was his theory that it was better to pour a mould at as low a temperature as possible. In such a case there would have to be very large runners, as well as an extended use of risers with sand castings.

One difficulty in regard to the absorption of iron in aluminium was the steeping in of the metallic elements when using a plunging-in method, as there would be a washing away of the plunger. What steel did Mr. Wells use for his plungers, because this was a difficult problem to solve in many cases? He, the speaker, had tried molybdenum steel, cobalt steel, and various other steels, but there still remained the washing away of the plunger and the skimmers used for aluminium alloys.

Repeated Meltings

There was also the question of the repeated melting of Alpax Gamma with and without flux additions. In the repeated melting there was an addition of flux and the time factor and the liberation of the gas in one instance, but there was no flux in the other instances, and the result was that there was gas absorption. Was there a particular gas absorption with the number of remelts? Aluminium alloys were used for die casting. In some of the slides exhibited there was a greater shrinkage in an alloy which had been degasified than in one which had a large gas content. It had been found that in making die castings from aluminium alloys it was preferable to have a little gas present, because there was less shrinkage at the same time as quick solidification. There was no pinholing, there was not such a large grain size, and there was a sound casting.

MR. WELLS remarked that Mr. Phillips mentioned the flux treatment of silicon-aluminium at particularly high temperatures, stating a temperature of 1,060 deg. C., which was consistent with the soda-ash modification process. He thought Mr. Phillips was confusing the refinement of the microstructure with the macrostructure, which is quite a different thing. He agreed that in this case there was refinement of the microstructure at high temperature, but if the macrostructure was examined, it would be found that there was a particularly coarse grain for the reason that it was treated at a very high temperature.

With regard to the material for such tools as plungers, skimmers, etc., Swedish heat-resisting iron was one of the best materials to use, but it was not obtainable at the present time. The next best thing was to use a cast-iron plunger with the original cast skin intact and coated with a protective wash; it seemed to give the best service. The next point was in respect to Alpax Gamma and the possibility of gas absorption on repeated remelting. His experience was that any gas pick-up was entirely dependent upon the conditions under which the remelting was carried out.

Dealing with gas in relation to die casting, he had mentioned the exercise of discretion when applying de-gassing treatment. The rapid rate of cooling helped because a greater amount of gas could be present without pinholes appearing. He had also mentioned that, with the gas removed, the feeding problems became greater. When dealing with die castings, it was better to carry as much gas as was practicable in order to offset some of the shrinkage difficulties which might occur.

Copper-Free Alloys

MR. D. FLEMING said that the first point he wished to raise concerned the list of materials given by Mr. Wells when he was discussing the grain refining effect of niobium. The remark was made that the aluminium-zinc alloy was copper free. Was there any great significance in the fact that it was copper free? His second point was whether the gassing of metal was caused by metal which had already been gassed. This was a point which had already been brought out several times. As he understood it, the gas solubility curve showed there was a sudden decrease in the solubility in freezing. Therefore, the maximum of gases the metal carried under normal cooling, once it was frozen, should be in equilibrium the second time the metal was allowed to solidify.

Was it possible actually to gas metal by using metal which had previously been gassed? Did it still increase the danger of gassing the second time? What was the reason for using a steel-sheathed pyrometer? While he could fully appreciate the usefulness, from the foundry point of view, of metal partially gassed for even normal castings to a certain degree in order to obviate shrinkage difficulties, was there any data on the effect on mechanical properties in allowing the retention of gas? Surely the effect must be a submicroscopical porosity.

MR. WELLS replied that the fact he mentioned aluminium-zinc alloys which were copper-free was merely incidental. It happened to be the case that he had checked them, and they were mentioned for no other reason. It was not intended to emphasise the copper-free nature of the material. With regard to the question of gas absorption by the addition of gassy metal to a melt, he thought it was correct to say there would be gassed metal from a crucible of metal which was substantially gas-free at the start. There was, in fact, damage done to the metal in the crucible by making the addition.

The point with regard to a steel-sheathed pyrometer was that it would be found that readings would be upset through the attack of the flux in the case of the chromel-alumel type of thermocouple. A very considerable flutter was caused and a constant reading could not be obtained. Therefore, it was uncertain what the reliability was. The alternative was to use a steel sheath protected by a suitable wash. In further reply to Mr. Fleming, Mr. Wells said he was referring in all cases to a couple which had a welded junction.

MR. FLEMING said he had encountered a similar difficulty owing to the interference of slag on the reading. He wondered if that was the reason.

MR. WELLS, continuing, said the answer to Mr. Fleming's earlier question was that, as long as there was no visible porosity, the effect on mechanical properties was nil, because the gas was retained in solution. As long as there was freedom from porosity, the gas had no effect on the properties.

MR. FLEMING said he had somewhat of a doubt with regard to the de-gasser. His own opinion was that it was due to the smallness of the hydrogen atom which it was quite possible to hold within the lattice of the heavier metal atoms. He was rather intrigued with the idea of the larger bubbles sweeping up the hydrogen bubbles when the hydrogen bubbles were actually trapped within the lattice of the metal material. He wondered, with Mr. Phillips, whether the effect of the salts was merely to de-gas.

MR. WELLS would not like to say that the mechanism of these things was completely understood; but it had been demonstrated, both by himself and by other people, that to all intents and purposes the gas was removed.

MR. PHILLIPS inquired how niobium compared with titanium for price.

MR. WELLS said he had not studied the price angle, but he did not think there was very much in it. There was rather less of niobium required. Most of the alloys he had used contained substantial amounts of iron, and allowed the use of ferro-niobium for making the hardener.

MR. S. STANWORTH asked if Mr. Wells could give any information as to what would happen when the water vapour decomposed. Very small pieces of oxide must be formed in the metal. As a general rule, the fluidity of aluminium alloys was reduced each time they were remelted. It was to be imagined that this effect was due to the formation of oxides. The specific gravity of the oxide increased as the temperature increased, so that if the temperature of the aluminium was raised above 750 deg. C., the oxide tended to be heavier and to settle down to the bottom. When working at high temperature, it was to be imagined that it would be very much more difficult to get rid of the oxides. Was there any efficient means of doing so, once they had got into the aluminium in such a microscopic form as in the case of water vapour? It was to be imagined it was a case of suspension similar to a colloidal solution.

MR. WELLS said that the dissolution of the water vapour was more or less at the surface, and therefore did not necessarily lead to oxide troubles.

MR. PHILLIPS: Do you not get atomic hydrogen in that instance?

MR. WELLS: Yes.

Heavy Magnesium Losses

MR. E. LONGDEN said that, in regard to the manufacturing of some magnesium alloys carried out in U.S.A., the conclusion was arrived at that there was something like 25 or 27 per cent. loss of the alloy. He wondered what was the loss. Mr. Wells had referred to different heatings, and it would be interesting to learn how much metal was left. The hydrogen would not account for the loss of metal.

MR. WELLS said that the flux itself was removing the magnesium. In one series of remeltings, where the flux was absent, no changes occurred in composition; in the other only slight losses were recorded.

MR. LONGDEN asked if Mr. Wells considered oxidation was taking place.

MR. WELLS replied that there was oxidation in the absence of flux, but it was not very selective, otherwise serious losses of magnesium would occur on remelting if there was selective oxidation of the magnesium.

MR. PHILLIPS thought there might be a somewhat analogous effect to the addition of sodium carbonate on iron in order to remove sulphur. There was a similar method of adding sodium fluoride and carbon to a melt and then getting an affinity with magnesium. He was merely theorising.

MR. WELLS said that it was the flux which was doing the damage and removing the magnesium. This was indicated by the fact that straightforward melting did not cause losses, at any rate, to the same extent.

Aluminium Losses

MR. J. R. DAY inquired whether it was not necessary to exercise considerable care when pouring the finished alloy from the melting vessel; for instance, a large amount of oxygen was taken up during the transference of aluminium through the atmosphere to the receiving vessel. There must be a loss of usable metal. What was the extent of it? It was well known that the greater the drop taken by aluminium the greater the loss there would be through oxidation. What was the safest distance to allow the metal to fall so that the greatest amount of loss in the aluminium could be eliminated?

MR. WELLS said that the drop through the air must be reduced to the lowest possible extent consistent with being able to carry out the work. He could not state any figures obtained through actual practice.

MR. DAY said it would be rather hard on a man who was dealing with 200 lbs. of aluminium to find he had only 195 lbs. left when the job was finished.

MR. WELLS agreed; but it would be stressing the point very much indeed to assume such a loss as that. It could not be very much more than something of the order of 1½ per cent. to cover both actual melting losses and oxidation of the kind mentioned.

MR. DAY said it had been mentioned in the course of the discussion by one speaker that he advised raising the temperature of the alloy to a very high degree and de-gassing in that way. Was there not a tendency to lose magnesium by so increasing the temperature, or would it always be stabilised?

MR. WELLS said that the alloy referred to did not contain magnesium.

MR. LUDLOW remarked that Mr. Wells had dealt with what might be termed high-strength alloys. In wartime certain alloys were thrust upon the industry which were not as good in some respects. He was thinking particularly of D.T.D.424. Had Mr. Wells any information to offer concerning that alloy—as to what precautions must be taken in casting up and any other allied problem?

MR. WELLS replied that the ordinary normal precautions associated with the handling of high-grade materials will ensure the best results with D.T.D.424. He could not offer any special information.

MR. A. PHILLIPS said that D.T.D.424 was a poor alloy with which to work; to get the tests of 9.0 tons ultimate and 2 per cent. elongation was very difficult. The addition of titanium to D.T.D.424 was one of the best ways he had found.

Burning of Aluminium

MR. E. CLEGG said there seemed to be quite a theory among foundrymen that aluminium could be burnt; in other words, it could be raised to such a high temperature that the metal could be ruined. Was this possible? Further, he would welcome an expression of opinion concerning the reverberatory melting of aluminium alloys. Was this a really practicable form of melting? A number of furnaces were on the market for this particular type of work. When alloys were used for die-castings they were generally very high in zinc content. Was the elongation always low, and was it practicable to make it any better? A further point upon which he would like information was whether the removal of zinc from an aluminium alloy was practicable. Was there any method whereby the zinc content could be lowered?

MR. WELLS said that, with regard to the burning of aluminium, he did not know what temperatures Mr. Clegg had in mind, but he had more or less shown what might happen as a consequence of using high temperatures. There was the question of grain coarsening and the absorption of gases if conditions were favourable in that respect, but he did not quite understand what was meant by the term burning. As far as deterioration was concerned, it was a question of excessive oxidation; there was possibly excessive gas taken up, and grain coarsening in the absence of a refiner, or it was possible, by going high enough, that the refiner would not be effective. He had gone to about 900 deg. C., but there was no necessity for that temperature in the ordinary way.

MR. CLEGG said that with reverberatory melting there was sometimes a flash-off. There was excessive oxide in a reverberatory furnace, and it automatically generated heat. When such conditions occurred, there might be metal in the furnace which actually came out in the aluminium. Was that metal still useful? By the addition of titanium, or anything else, could it be brought back to the condition of workable material?

MR. WELLS had not had any experience of dealing with the melting of aluminium alloys in reverberatory furnaces, though he knew the method was employed very often. He could not appreciate the condition the metal was in.

MR. PHILLIPS said that if it was left in the furnace until the metal was in the neighbourhood of the correct pouring temperature, the metal would be satisfactory when melted in a reverberatory furnace.

Zinc Content

Mr. Wells disagreed with the statement that most of the aluminium alloys used for die-castings contained high zinc. Generally speaking, people liked to keep their zinc contents low for die-castings, because of the hot shortness tendency. He regretted he was not in a position to offer any advice concerning the removal of zinc.

Mr. Fielding said that the theory of hydrogen absorption was a very old one. He could quite well understand it to be the case in connection with the ingots, when they were not altogether free from moisture or oxide. What he was puzzled about was the absorption from the wet coke or from the foundry atmosphere. He would like to have a little more light thrown upon this old theory.

Mr. Wells said it was a fact that, when water vapour was present, the trouble did occur. The gas absorbed as a result had been analysed and had been found to be hydrogen. There did not seem to be any doubt about it.

Mr. Fielding asked whether it was proved that the hydrogen had been taken from the atmosphere or whether it was present in the original ingot.

Mr. Wells said it had been proved that hydrogen was absorbed from the atmosphere when the conditions were such that water vapour was present.

Mr. Fleming thought it was correct to state that in cases of metal equilibrium the presence of a gas such as CO_2 had very little effect upon the equilibrium between the hydrogen and the metal. The balance was purely a question between the metal and the hydrogen and the further gas had no effect upon the equilibrium.

Mr. Wells agreed.

Mr. A. Phillips said that in an exchange Paper from a German writer it was definitely proved that there was absorption of hydrogen in the aluminium alloys. This Paper was received by the 1938 Conference.

Grain Size and Strength

Mr. E. R. Waddington inquired whether there was any relation between grain growth and heat-resisting qualities. In the case of a job like a light piston for an aero engine, would it be advisable to maintain a large grain or a small grain?

Mr. Wells thought that a coarse grain should never be countenanced in any casting of that sort. A piston was working at elevated temperature, and coarse-grained material was definitely very much weaker than that which was of fine grain. For mechanical strength reasons coarse-grained material should not be used for such things as pistons.

Mr. H. Marsden asked, with respect to die-casting and titanium, what quantity of titanium should be added.

Mr. Wells said there was no necessity to keep on adding titanium; it was not lost. All that was necessary was to look after the stirring, so that the material at the bottom of the crucible was not enriched at the expense of the top by segregation. There was no point in making an addition; it was unnecessary.

Mr. G. R. Day thought the speaker had the ingot form in mind.

Mr. Marsden said he should have mentioned D.T.D.424.

Mr. Wells said that the amount of titanium added should be of the order of 0.15 per cent. Once it had been added, there should be no further addition; it was not lost. The only tendency was segregation, which was overcome by frequent stirring during the process.

Mr. Day asked whether there was any possibility of absorption of hydrogen from the mould by the metal in the case of green-sand or dry-sand moulds.

Mr. Wells said there was in some materials; they were usually those containing rather high magnesium contents—the D.T.D.300 type. He did not think there was any particular trouble in the case of other types of alloys.

Mr. Wells was accorded a very cordial vote of thanks, on a proposition made by Mr. A. L. Key, seconded by Mr. N. Greenwood.

DISCUSSION—LONDON BRANCH

Iron in L.33 Alloy

Mr. W. A. Jones referred to the iron pick-up of alloy L.33 from the iron pots, saying that a good deal of L.33 alloy had a high iron content; he had found that much depended on the length of time the material was left standing after modification. So far it seemed to him that, if the alloy had a high iron content, it must be left standing considerably longer than the period of from 4 to 7 mins., which was usual in the case of virgin material. He asked if Mr. Wells could confirm this.

The loss of magnesium when fluxing was another matter which interested him particularly. He had carried out a number of experiments on lines similar to those of Mr. Wells, with RR.50, but his figures did not quite bear out those given by Mr. Wells. He wondered how Mr. Wells' magnesium figures were estimated, for the method of estimation might have some influence. He added that he had found great difficulty in getting the magnesium out when he had wanted to do so, and that seemed to him to be rather strange.

Replying to a query by Mr. Wells as to the purport of his question concerning iron pick-up by L.33, **Mr. Jones** said that in the Paper the tensile strength of the new material was given as about 11 tons per sq. in., whereas the figure for the material melted in the iron pot was 9 tons per sq. in. The grain size of the 9-ton material was large, and it appeared to be of similar type to the secondary L.33, having a high iron content. In his experience the tensile strength of the material was higher when the period during which the material was allowed to stand was increased. For example, with the virgin material, as illustrated by Mr. Wells, the grain size after about 3 mins. was quite large; but when the standing period was from 7 to 10 mins., the material had a fine silky structure.

"Grain Size" and Structure

Mr. Wells said there seemed to be a good deal of misapprehension as to what was meant by the term "grain size." The modification process was one of structural refinement, not of grain refinement; those two seemed often to be confused.

Mr. Jones agreed, and said he was referring to the structure. As had been indicated in the Paper, the structure was influenced by the amount of iron in the material; but he felt that the structure could be altered by a longer waiting period during the modification.

Mr. Wells said he had noticed that, if the iron content were a little on the high side, there was a tendency for it to segregate in the areas showing the better modification. The experience was that such a long standing period was definitely detrimental, as shown by test results. The deterioration in the state of the modification due to prolonged standing appeared to accentuate the segregation of the iron as the well modified areas decreased.

Mr. Jones commented that many investigators who had started with an alloy having a very high iron content had claimed that ultimately they had achieved a tensile strength of 11 tons per sq. in. in the alloy.

He had found it possible to achieve high tensile strength only by waiting for a period.

MR. WELLS replied that one could secure the desired properties with an alloy having an iron content of 0.6 per cent., the maximum quoted in the specification. The alloy he had referred to in the Paper had contained 1 per cent. of iron. There was great difficulty in removing the last traces of magnesium from aluminium alloy; it was not difficult to reduce the magnesium content from large to quite small quantities, but the removal of the residual magnesium did present great difficulty. The task of determining the magnesium content was undertaken by the chemists, and he believed the method used was about as accurate as any. The determinations were made chemically, not spectrographically.

MR. HUDSON (J. Stone & Company) said that the phosphate method was used for determining the magnesium content; while it was not claimed that that method was infallible, he and his colleagues considered it to be the best method.

Casting Section and Grain Refinement

MR. F. HUDSON, after expressing his appreciation of the Paper, asked for more information concerning the effect of niobium and titanium as grain-refining elements in the production of light alloys. He sought information on the relation of casting section to grain refinement, and asked if Mr. Wells had found it necessary to apply grain refinement to die castings. Further, he asked if grain refinement were necessary in the production of heavy-section castings, in view of the fact that usually they were poured at a temperature below that at which coarsening arose.

MR. WELLS recalled that in the Paper he had stressed the importance of melting temperature in relation to the grain size of the castings. It stood to reason, he said, that if the founder did not exceed the critical temperature for a given alloy, the material could be kept fine; but the fact remained that it was very difficult, particularly in the case of die-castings, to keep the melting temperatures sufficiently low. Therefore, it was necessary to grain-refine when producing die-castings and chill castings. It had been noticed many times that when the metal had been somewhat maltreated and melted at a temperature higher than was essential, coarse grain had resulted when there was no grain refiner present; when one tried to cast into dies all sorts of cracking troubles occurred, and they could not be eliminated, owing to the inherent weakness of the coarse grain at the temperature just below the freezing point, when the non-giving nature of the metal die held up the casting so that it was not free to contract. The use of a grain refiner for alloys used for die-casting was certainly a great asset and was to be recommended.

The same considerations applied to the making of heavy-sectioned sand castings. If one were able, throughout the whole history of the metal, to keep the melting temperature low enough, one could produce a heavy casting having a reasonably good grain without the use of a grain refiner, by reason of the relatively low pouring temperature. But inasmuch as a grain refiner assisted by reducing shrinkage, helped to overcome feeding troubles, and so on, there was no question that the use of a grain refiner was of great advantage. His view was that all such alloys as he had discussed should carry a grain-refining constituent, whether the founder was sand-casting or die-casting heavy sections or light sections.

Pinholing Troubles

MR. F. A. HOULT asked what was the relation between pinholing due to hydrogen pick-up and pinholing due to sodium modification. Speaking generally, would Mr. Wells blame hydrogen pick-up or sodium modification as the main cause of pinholing?

MR. WELLS said it was due to hydrogen pick-up every time.

MR. HOULT, who was asked to mention a particular case, said that even in a die-casting in L.33 there was pinholing, and he wondered whether hydrogen pick-up was responsible in that case.

MR. WELLS asked if Mr. Hoult usually found pinholing in L.33.

MR. HOULT replied that he did, in certain sections.

MR. WELLS said that it was due in the first instance to hydrogen in the metal, and the fact that pinholing did not show in some die-castings, *i.e.*, in the thinner-walled castings as distinct from the thick-walled castings, was controlled by the rate of cooling. Assuming that one were using the same metal for both, in the case of the thin-walled castings the gas was satisfactorily held in solution, whereas in the heavier section, by reason of the slower rate of cooling, the gas came out of solution and showed up as pinholes. The rate of solidification entered into the problem when gas was present.

D.T.D. 304

MR. HOULT, discussing melting conditions for D.T.D. 304 and methods of preventing hydrogen pick-up, asked if it were general practice to use electric furnaces and, if so, why could not D.T.D. 304 be produced satisfactorily in a bale-out furnace. Was the choice of furnace connected with the problem of hydrogen pick-up?

MR. WELLS replied that he had not experienced serious pinholing in D.T.D. 304, and he did not consider that gas pick-up was the greatest difficulty in connection with that alloy; there was not a great deal of trouble as a rule in producing D.T.D. 304 in a pinhole-free condition. One trouble was that the total impurities contained in the material must be controlled; and, further, the nature of the material was such that it was difficult to feed, and it was also difficult to avoid cracking. In his experience gas porosity was not a great source of trouble with D.T.D. 304, whether one used an electric furnace, a bale-out furnace or any other type.

MR. HOULT commented that he had not experienced serious pinholing in D.T.D. 304, but he had put the question as one of general interest, in order to secure information.

MR. WELLS added that it was quite easy to flux-treat the material in order to eliminate pinholing, if one were troubled with it.

MR. E. W. HALE said that founders who were using bale-out furnaces for melting D.T.D. 304 were not experiencing pinhole trouble in their castings. On the other hand, electric furnaces were used by a few founders who claimed that, due to the absence of water vapour in the melting chamber, there was no gas pick-up. If one used a furnace in which the metal was completely protected from the products of combustion, there could be very little risk of hydrogen pick-up by the metal.

Poor Feeding Causes Insidious Shrinkage

MR. E. RAYBOULD confirmed Mr. Wells' statement that there was no undue gas porosity in D.T.D. 304; indeed, he believed that gas porosity was a little less in that alloy than in most others. He had expected some reference to D.T.D. 304, because there was a strong demand among designers for castings to replace forgings, and designers were looking to the high-strength alloys for that purpose. But the great bugbear which impressed the aluminium foundrymen in regard to the high-strength casting alloys was shrinkage. In the smaller castings the problem was relatively easy of solution, because there it was possible to achieve conditions of progressive solidification; but in the large castings there was increased difficulty, especially where sections were thick. If there was the least fault in the mould design, shrinkage would occur, perhaps because the risers were not large enough or because progressive solidification could not be achieved. Shrinkage due to inadequate feeding was of a most insidious form, occurring probably throughout the casting; and he believed it contributed to cracking, because there were grain boundary weaknesses. The subsequent heat-treatment was a little drastic, so that if cracking did not occur before that, it was likely to occur afterwards. However, he would not contribute to the view that D.T.D. 304 was very prone to gas porosity, but emphasised that if the founders would take sufficient trouble they could overcome much of the difficulty.

The CHAIRMAN (Mr. R. B. Templeton) said that apparently Mr. Raybould's opinion was that the difficulties were concerned more with foundry technique than with the metallurgical aspect.

Difficulties in Casting

MR. RAYBOULD replied that in respect of metallurgical conditions the high-strength casting alloys did not give the latitude that was given by some other alloys; the more ambitious foundrymen became to improve the properties of the high-strength castings alloys, the more difficulty there would be in casting components in them satisfactorily. But much of the difficulty could be overcome by the adjustment of foundry conditions, *e.g.*, the proper positioning of runners and risers, and the proper use of chilling effects. In die-castings, at least of the smaller types, there were not great difficulties, although again there was the liability to shrinkage and, of course, the metal was very hot-short and there was danger of the occurrence of manipulative cracking during the withdrawal of a casting from the die, more so than in many other alloys. He asked for Mr. Wells' opinion on that, because D.T.D. 304 was possibly the most popular high-strength casting alloy at the moment, or at any rate it had the greatest demand. He also asked how it compared with D.T.D. 300 (the 10 per cent. magnesium alloy), and whether Mr. Wells had found the latter more or less difficult to cast than D.T.D. 304.

MR. WELLS commented that D.T.D. 304 seemed popular on one side of the fence, but not on the other; the designer wanted it, but the founder did not. He agreed with Mr. Rayboult that it was possible, if one could give the necessary time to it, to produce good castings; but in view of the demand for production under present circumstances one could not give the necessary time to the production of complicated castings in alloys of the D.T.D. 304 type. He refrained from expressing a definite opinion as to the relative casting qualities of D.T.D. 304 and D.T.D. 300, for he had not done very much with D.T.D. 300, and such experience as he had had was not altogether plain sailing. But the casting of both alloys was difficult, and one needed considerable experience before one could get very far with them. It was true that the main difficulties with D.T.D. 304 were the cracking and shrinkage tendencies, and not gas porosity.

Melting Methods

MR. W. A. TURNER, reverting to Mr. Hoult's question concerning the melting of D.T.D. 304 in an electric furnace as compared with gas or oil or other types of furnace, said he was not quite sure whether or not Mr. Wells insisted that there was no more difficulty in melting the alloy in other types of furnace than in the electric furnace.

MR. WELLS replied that there was always danger of gas pick-up if the conditions were not too good; but, of course, that applied to all aluminium alloys. Electric furnace methods were the ideal, but few founders were able to use electric furnaces; and they must make the best of the facilities they had at hand. D.T.D. 304 did not present more difficulty in relation to gas pick-up than did other alloys.

MR. TURNER asked if there were more difficulty from the general point of view in melting D.T.D. 304.

MR. WELLS said that definitely there was not.

MR. HOULT covered his earlier remarks on the subject by emphasising that he was not troubled with gas porosity in D.T.D. 304, because he melted it in an electric furnace. He had succeeded in his purpose in raising the subject, which was to widen the discussion.

Cause of Porosity

MR. G. C. PIERCE (Past Branch-President), referring to L.33 alloy, asked if Mr. Wells still considered that porosity was due entirely to hydrogen, and not to the introduction of sodium.

MR. WELLS replied that he did. The ingot received by the founder probably contained quite a considerable amount of gas, and the whole trouble was probably due to hydrogen.

MR. W. A. JONES asked if he would rule out the suggestion that the porosity might be due to sodium vapour, bearing in mind the shape and colour of the holes, and so on.

MR. WELLS said that he would. He added that the crystallisation characteristics of Alpax type alloys were different from other alloys; that was why the cavities had a different shape.

MR. JONES commented that he had seen both types of hole in the same casting.

MR. WELLS said he still considered that the porosity was due to hydrogen.

MR. J. P. P. JONES asked for Mr. Wells' views concerning increased porosity at certain times of the year, due to the increased humidity of the atmosphere.

MR. WELLS agreed that it played a part; if humid atmospheric conditions prevailed for a lengthy period, gas troubles appeared to increase in the foundry. It seemed that it must revolve around the same point, that the water vapour would be decomposed, and the hydrogen picked up by the metal.

MR. J. P. P. JONES asked if that occurred after degassing, *i.e.*, during the very short period between degassing and pouring.

MR. WELLS would not go so far as to assert that that was so.

MR. G. C. PIERCE asked how far it was possible for hydrogen contamination to occur, due to pick-up from the oil fuel, when using an oil-fired furnace.

MR. WELLS replied that, when using a properly-controlled oil-fired furnace, there was not much danger of such contamination.

MR. A. J. MURPHY (Branch Vice-President), commenting on Mr. Wells' reference to contamination due to the entrainment and retention in the molten metal of non-metallic impurities, such as portions of refractory pots, and so forth, said that one came across isolated instances of it, and one wondered why, if it could occur once or twice, it did not occur more frequently. One suspected that the rather subtle surface tension effect was at work, as the result of which those particles of fireclay material, etc., would neither float nor sink in the metal. It would be interesting to hear Mr. Wells' views on that, as well as the experience of others.

Cast-Iron Pots

The CHAIRMAN asked what degree of contamination resulted from the use of a cast-iron melting pot, and if Mr. Wells could suggest any particular specification for the cast iron of which the pots were made, in order to minimise the danger of iron pick-up.

MR. WELLS replied that that depended on the temperature, the time and the maintenance or otherwise of the protective coating. Alloys which were sensitive to iron pick-up could be spoiled quite easily by damaging the protective coating, by bad manipulation of the stirring rod, and so on. The alloys had a great affinity for the iron. For the pots, ordinary grey cast iron, with the original casting skin left intact beneath the protective coating, afforded as good a protection as could be obtained. He did not think that heat-resisting irons had proved to be any better.

Minimum Temperature for Hydrogen Absorption

MR. HOULT asked what was the lowest temperature at which aluminium alloys would absorb hydrogen.

MR. WELLS replied that hydrogen was absorbed all the way up the temperature scale, once the metal was molten. The rate of absorption was very slow at the lower temperature, but at temperatures above 750 deg. C. it was necessary to be on the look-out for trouble. At 700 deg. C. the hydrogen pick-up was so slow and so small that, generally speaking, one had not to worry a lot. That was why, in respect of some alloys, 700 deg. C. was stated to be the optimum temperature; the purpose of stating that temperature was to avoid conditions favourable to hydrogen pick-up.

MR. HOULT said he had in mind the use of oil as a spray on mould surfaces in order to prevent the skin drying, and the absorption of hydrogen by the metal when it was flowing over sand which had a thin coating of oil.

MR. WELLS did not think that a lot of hydrogen was picked up by the alloys from the mould itself, except perhaps in the case of certain classes of alloys, such as the D.T.D. 300 type, having the higher magnesium contents. When casting such alloys one was usually forced to use special sands in order to counter the tendency to pick up hydrogen.

The CHAIRMAN recalled Mr. Raybould's interesting comments on the matter, and asked whether alterations were made in the methods of gating and risering, according to the alloys concerned. Was there a wide divergence of practice in the methods of gating?

MR. WELLS replied that each alloy must be dealt with on its particular merits and characteristics. There was a fairly wide divergence in respect of the methods of gating as between one type of alloy and another. One would not deal with an alloy of the L.33 type in the same way as a high-strength material.

Vote of Thanks

MR. H. W. LOCKWOOD (Branch-President), who apologised for the fact that he was unable to reach London in time to preside at the meeting, and thanked Mr. Templeton for having stepped into the breach, proposed a hearty vote of thanks to Mr. Wells for his excellent Paper. Recalling the factors which had led to the meeting, he said that the London Branch, he believed, was the largest in the Institute, and the Branch Council, on analysing the membership, had appreciated that a quite large proportion of the members were concerned with non-ferrous founding. In consequence, a sub-committee was formed to arrange a programme of Papers. Mr. Wells had responded to the invitation to lecture, and there was no doubt that he was a unique lecturer; appreciation of the service he had rendered could not have been better shown than by the fine attendance at the meeting.

DR. A. B. EVEREST, seconding, commented jocularly that to him, as one concerned mainly with the ferrous side of the industry, the meeting had been a source of some consolation. The ferrous founders talked about blowholes in cast iron, and perhaps they had come to regard themselves as being on a lower plane than the non-ferrous founders. But, having listened to Mr. Wells' Paper and the discussion upon it, there seemed to be as many kinds of blowholes in aluminium as in cast iron! However, the Paper had been most interesting, and the members of the Branch were most appreciative.

The vote of thanks was accorded with acclamation, and Mr. Wells assured the meeting that the preparation and presentation of the Paper had afforded him great pleasure.

MR. HOULT said he would endeavour to persuade a colleague to present a short lecture on D.T.D. 304 alloy. To do so might appear to be inviting an avalanche; but the avalanche might be of interest, and he would undertake to exhibit various samples and X-ray photographs which had been produced during the past few months. Commenting on the comparisons made between the problems of ferrous and non-ferrous founding, Mr. Hoult said that perhaps the non-ferrous founders had greater opportunity of finding out their faults, when they had to produce Class I castings which were subjected to examination by the A.I.D. radiological technique.

Lancashire Branch **Paper No. 787**

Fluid Pressure in Foundry Practice

By E. LONGDEN,* M.I.Mech.E. (Member)

Fluid pressure plays a very important part in the production of castings. It is, therefore, a subject which should receive more attention by both the practical and technical foundrymen. These notes are compiled with a view to focussing attention on to the subject, and provoking, it is hoped, a useful discussion. First, a detailed examination of the excellent data published by Howard F. Taylor and Edward A. Rominski of work carried out in a Naval Research Department in the U.S.A. is recommended. The subject is "Utilising Atmospheric Pressure in Making Steel Castings,"† and it has been dealt with in a most scientific manner. Further brief references will be made to the work during the course of these notes.

The best known methods of exerting more than normal pressure on solidifying metals are by the various centrifugal and pressure die-casting processes. In these processes, pressures up to 100 atmospheres result from the forces employed. No emphasis is needed to extol the high qualities of castings made by either of the processes named.

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* Foundry Manager, Craven Brothers (Manchester), Limited.

† Trans. A.F.A., Vol. 49, 1942, p. 215; see also "Foundry Trade Journal," October 15, 22 and 29, 1942.

In the year 1865 Sir Joseph Whitworth introduced a method of casting steel ingots under pressure. A similar process is stated to have been used by Bessemer as far back as 1856. The process consisted of pouring metal into a mould consisting of a strong steel jacket with a more or less porous lining. Steel was run into the jacketed mould, and great pressure put on it by means of a hydraulic ram, the pressure reaching up to 20 tons per sq. in. of horizontal section. As the pressure is exerted, there is a vigorous escape of gas and flame. The pressure results in a considerable reduction in the size of the ingot.

In the Whitworth process, pressure is applied at the top, but in a later application of high pressure by the use of mechanical devices introduced by Robinson and Rodger, of Sheffield, and Illingworth, of New York, U.S.A., the pressure was applied laterally. The moulds were made in halves. Initially, the half-moulds are held apart by packing, the packing being removed after a certain depth of solid metal had formed on the outside of the ingot in contact with the mould. The lateral pressure was then applied by hydraulic power.

Other means of exerting pressure are by employing carbon dioxide, air and steam. All these methods date from 50 years back, although there have been various modifications since to make the processes more commercially practicable, and scientific minds have recently addressed themselves to the problems. When the war is over the public will learn more of the spurt given to production methods by the application of science and technology generally. This is on the credit side of war and, God willing, the world would be better without war to secure such comparatively small benefits.

Aspects Needing Examination

Any consideration given to the influence of fluid pressure on the mould and casting must necessarily take account of and associate, at least, the following aspects:—

(1) What is the definition of fluid pressure? (2) What are the effects of fluid pressure on the different classes of moulds? (3) What are the effects of fluid pressure on the quality of the metal and the casting? (4) What methods are adopted in the construction of moulds to reduce the inherent weakness present in moulds, especially when made in sand? (5) What methods are adopted to secure cores in moulds to prevent their flotation or movement?

But the various influences are so wide in extent that it is impossible to deal adequately with all aspects. Therefore, only brief references can be made to methods of control practised in the construction of moulds and cores to resist fluid pressure, especially methods to secure cores. Hydromechanics covers the properties of fluids, and it is divided into two divisions; the first division deals with fluids in equilibrium or at rest, and the second with fluids in motion.

THEORY AND LAWS OF FLUID PRESSURE

A fluid is defined as a body which exercises no permanent resistance to change of shape. It will, therefore, ultimately take up the shape of any vessel in which it is placed. Fluids are divided into two classes—liquids and gases—a further conditioning factor being the degree of viscosity.

(*a*) A liquid is a fluid, the volume of which does not increase indefinitely as the force upon its surface is reduced. A fluid, therefore, will take the shape of any vessel in which it is placed and will have a free surface.

(*b*) A gas is a fluid, the volume of which increases continually as the pressure is reduced—in other words, it is compressible. A gas is, therefore, an elastic fluid. In consequence gas possesses no free surface and will completely fill any vessel in which it is placed

(*c*) Viscosity or viscidity of a fluid may be defined as the degree of resistance to flow, or tenacity, glutinousness and stickiness. A perfect fluid will have zero resistance to change in shape. The degree of fluidity of various metals and alloys plays a very important part in obtaining sound castings.

Liquids

A liquid at rest cannot exert a pull or tangential force. Therefore, the forces to be considered are those of thrust. A thrust across a unit area is called pressure. If the thrust across every square inch of an area is the same, it is not difficult to find the pressure across the area if the thrust across one square inch is known.

When a fluid is at rest the pressure at any point is perpendicular to the surface with which it is in contact. The pressure of a fluid at any point is the same in all directions, pressing equally in all directions, not only from the top to the bottom like a solid body, but also exerts a pressure laterally in proportion to the height and weight of the fluid. Pressure increases uniformly with depth increase below the surface and varies as the depth. Pressure applied to the surface of a fluid is transmitted without change of intensity to all parts of the fluid.

The force a liquid exerts on the base of a vessel is independent of the shape of the vessel, and depends only upon the area of the base, depth, and specific gravity of the liquid. With a body placed in liquid, every small area of the surface of the body in contact with liquid acted on by force will vary with the depth of the area below the surface of the liquid. One can imagine a body below the surface of a liquid consisting of a fluid of the same density as the liquid itself and its equilibrium under the action of its own weight and fluid pressure. The weight of the liquid displaced by the immersion of a solid body in a fluid is equal to the weight of the solid body. The centre of gravity of the liquid is called the centre of buoyancy, or the centre of gravity of the fluid displaced. The buoyancy of a liquid on a body does not depend upon the depth the body is immersed, provided that the specific gravity of the liquid does not vary.

Gases

Gases are described as elastic fluids. If a quantity of gas is placed in a closed vessel of any size, it will extend itself to all parts of the vessel. This capacity of expanding indefinitely is a peculiar property of gas by which it is distinguished from a liquid. A liquid when placed in a vessel will acquire the form of the portion of the vessel it occupies, according to the law of gravity, but there will be no appreciable change in volume. Since any fluid (liquid or gas) exerts pressure at every point of surface with which it is in contact, it follows that gas will exert pressure at every point of the vessel within which it is contained, whereas a liquid will not exert pressure on the upper surface of a containing vessel within which it is contained if the vessel is not completely filled, the upper surface of the vessel being free. The volume of a given mass of gas under constant pressure increases uniformly with increase in temperature and the amount of increase for all gases when expanding under rising temperature is equal 1/273 part of their volume at 0 deg. C.

FLUID PRESSURE IN MOULDS

The pressures to be considered in a mould are, firstly, that of liquid pressure, which embraces static and streaming pressures or momentum, and, secondly, gas pressure. Usually calculations are based on liquid pressure, but whilst gas pressures are difficult to ascertain, it is a force which must not be ignored, otherwise failure may follow. When moisture in a mould is converted to steam and gas and the temperature further raised quickly in contact with molten iron the increase may be of the order of several thousand times the original volume, depending upon the temperature gradient.

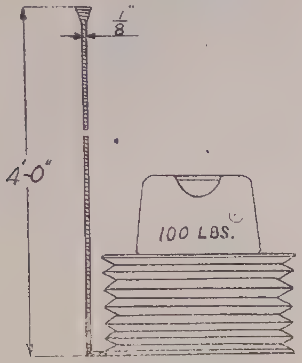

Fig. 1.—Hydrostatic Bellows.

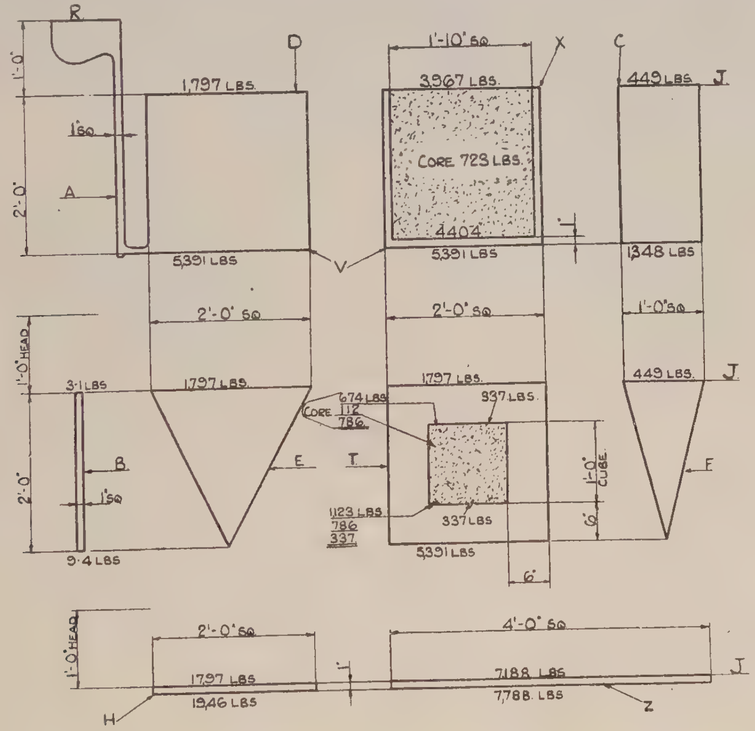

Fig. 2.—Series of Castings with Different Surface Areas.

The sand of a mould will hold gas-forming elements in, such as metallic oxides, combustible material and more or less moisture to which must be added the air occupying the mould cavity. A large portion of the gas formed will be evacuated through the sand pores and artificial vents provided by the moulder; further quantities of gas pass through the riser gates, but at the moment of complete filling of the mould, when the riser gates are just closed by the metal, gas pressure will exert a force in addition to that of liquid pressure. The degree of this pressure can only be allowed for empirically from acquaintance with the construction of moulds against fluid pressure. The author would suggest a minimum allowance of an additional 10 per cent. of lift on an average mould for gas pressure. In some cases, such as in certain types of moulds with open risers the gas pressure may be almost nil, but in another class of mould the gas pressure may be more than the 10 per cent. allowance suggested.

When considering the pressure exerted by a molten metal on a mould, the specific gravity of the particular metal is ascertained in addition to the greatest height of the head of metal and surface areas. Any pressure exerted will depend upon the height of the column of metal in the down-gate and pouring basin and not upon the actual volume. With a molten metal, however, the time during which it remains liquid is also important since pressure can only be maintained to act through feeding heads to allow for liquid shrinkage, if the area connecting the header with the casting has sufficient body and volume and delays freezing until the casting is satisfied.

Actual pressure is easily explained by a reference to a simple U tube with one leg having a 1-in. diameter and the other a 6-in. diameter. Water poured into the 1-in. section will rise into the 6-in. section and remain at the same level in each section. A typical example is that of the hydrostatic bellows, the sketch, Fig. 1, showing how a small quantity of water is capable of exerting great pressure. If a small quantity of water is poured into the $\frac{1}{8}$-in. diameter pipe which is connected with the bellows, the boards united by leathers will at first open a little, then when weights are placed upon the bellows and water poured in continuously until the $\frac{1}{8}$-in. diameter pipe is full through its 4 ft. of length, the weights will be raised. Though the water in the tube may weigh but a single pound, yet the pressure of this small quantity of water upon the water in the bellows will support the weights which may approximate 100 lbs.

Comparative Examples

In Fig. 2 is drawn a series of castings whose surface area varies, but which are all poured from a gate with the same head height. A is the down-gate of 1 in. square section fed from a pouring basin, R. The top of the pouring-bush metal is 12 in. above the joint line J, and the height from the effective base of the down-gate to the top of the pouring-bush metal is 36 in. Apart from the consideration of the cores in examples T and X, the series of castings B, C, D, E, F, T and X are of the same depth—24 in. below the joint line J. The examples H and Z depict plates 1 in. in depth; again in each case the castings are subject to the 12-in. head from the joint face to the upper surface of the pouring basin R. An average grade of cast iron is chosen to exemplify fluid pressures. Pressures will vary according to the densities of the alloy or metal. For other metals multiply the cast iron calculations by the factors in Table I. Taking cast iron at 0.26 lb. per cub. in., pressures are as shown in Table II.

It will be noted that the pressure on the upper faces of D, E, T and H are equal, although the volume of metal varies widely. The pressure on the upper faces of C and F are equal. The mean pressure on the sides of B, C, D, E, F, T and X is 6.24 lbs. per sq. in. The lift on the 12-in. cube core shown in example T is 337 lbs.; therefore requiring an additional force of 337 lbs. minimum to hold the core in its required position in the mould. It has been assumed in this example that the core is surrounded by metal. Of course, this is not practicable since an outlet from the core will be required to conduct away gases. It does, however, allow of a simplified expression of the influence of pressure.

When calculating the fluid pressure on moulds and cores, it is necessary to allow for the generation of the rapidly-expanding gases. An average of 10 per cent. is needed for gas pressure. The momentum of the metal when meeting upper faces of a mould needs further additional allowance of from 5 to 20 per cent., depending upon the open area of the mould and the speed of pouring. Flash formed on mould joints will increase the lift on the top box. When metal escapes from a mould joint the effect is to increase the lift progressively with the spread of the additional area covered by the flash or fin formed. Therefore, between 20 to 25 per cent. should be added to the calcu-

TABLE I.—*Factors for Various Metals.*

Steel, multiply by	1.09
Lead, multiply by	1.58
Leaded bronze (10 per cent. lead), multiply by	1.25
Phosphor bronze, multiply by	1.20
Gun metal, multiply by	1.18
Brasses, multiply by	1.16
Aluminium bronze (10 per cent. Al), multiply by	1.08
Average aluminium alloy, multiply by	0.37
Average magnesium alloy, multiply by	0.24

TABLE II.—*Pressures Imposed at the Points shown in Fig. 2*

Location of area of pressure.	Calculation.	Pressure, lbs.
B.—Section on the upper face at the joint J	1 in. by 1 in. by 12 in. by 0.26	3.12
B.— ,, ,, bottom of the mould	1 in. by 1 in. by 36 in. by 0.26	9.36
C.— ,, ,, upper face at the joint J	12 in. by 12 in. by 12 in. by 0.26	449
C.— ,, ,, bottom of the mould	12 in. by 12 in. by 36 in. by 0.26	1,348
D.— ,, ,, upper face at the joint J	24 in. by 24 in. by 12 in. by 0.26	1,797
D.— ,, ,, bottom of the mould	24 in. by 24 in. by 36 in. by 0.26	5,391
E.— ,, ,, upper face at the joint J	24 in. by 24 in. by 12 in. by 0.26	1,797
F.— ,, ,, ,, ,, ,, ,, J	12 in. by 12 in. by 12 in. by 0.26	449
H.— ,, ,, ,, ,, ,, ,, J	24 in. by 24 in. by 12 in. by 0.26	1,797
H.— ,, ,, bottom of the mould	24 in. by 24 in. by 13 in. by 0.26	1,947
T.— ,, ,, upper face at the joint J	24 in. by 24 in. by 12 in. by 0.26	1,797
T.— ,, ,, bottom of the mould	24 in. by 24 in. by 36 in. by 0.26	5,391
T.— ,, ,, top of the 12-in. core	12 in. by 12 in. by 18 in. by 0.26	674
T.— ,, under the 12-in. core	12 in. by 12in. by 30 in. by 0.26 Weight of core and pressure above core	1,123 112 674
T.— ,, ,, force or pressure required to hold the 12-in. core and prevent flotation		337
X.— ,, ,, upper face at the joint J	24 in. by 24 in. by 12 in.—22 in. by 22 in. by 12 in. by 0.26 and weight of core at 723 lbs.	3,967
X.— ,, ,, bottom of the core		4,404
X.— ,, ,, bottom of the mould		5,391
Z.— ,, ,, upper face at the joint J	48 in. by 48 in. by 12 in. by 0.26	7,188
Z.— ,, ,, bottom of the mould	48 in. by 48 in. by 13 in. by 0.26	7,788

lated pressure for variables and contingencies. When boxes or moulds are clamped or bolted together the factor of safety can be very large.

The effect of pressure on a weak and insufficiently rammed and reinforced mould is seen daily in any class of foundry. It will be noted that the pressure exerted on the bottom face of the 24-in. cube, example D in Fig. 3, is over $2\frac{1}{4}$ tons, and the pressure on the bottom face of the 4-ft. by 4-ft. by 1-in. plate, example Z (Fig. 2), is nearly $3\frac{1}{2}$ tons. The tendency for moulds to strain at points such as V in the example D, X and T, is pronounced, and must receive special attention to avoid a misshapen casting or even a complete run-out from the mould.

Influence of Fluid Pressure on Soundness

The pressure of the fluid head of metal has a very important effect on soundness in all metals. The greater the height of the fluid head of metal in the runner or riser gates, the greater the possibility of soundness in the casting. Whilst head pressure has little effect on refining or closing up the crystal structure of the metal, the influence on soundness is marked. It is due to the elimination of gases and gas pressure inside the moulds and cores. The head pressure forces gases to evacuate more effectively and speedily from the mould cavity through the riser gates, or pass through the natural and artificial vents provided in the mould and cores. This evacuation must take place before the metal has solidified in the runner, riser or feeder gates connections, so that metal may feed forward to take the place of the spaces occupied by gases under pressure.

The late evacuation of gases from moulds and cores is a greater cause of unsoundness than has yet been acknowledged or recognised by the average foundryman. If gases are slow to evacuate from a mould, the natural feed from the gates may be interfered with, due to a prior freezing of the metal in the gate connections. Finally, when the gas has vacated the various mould and core areas charged with gases, it may result in either distinct depression on the face of the casting or porosity may be disclosed after machining or when subjected to water or air pressure. Foundrymen will be impressed with the improvement to be made by applying the combination of ample head pressure in conjunction with generous gas outlets in moulds and cores, especially in difficult castings with complicated coring and design.

Influence of Atmospheric Pressure

Under this heading no one could do better than refer to the work of H. F. Taylor and E. A. Rominski in utilising atmospheric pressure to aid in the liquid shrinkage feeding of steel castings. The success achieved is based on arrangements made in the construction of a feeder head; in particular, on what are termed as "blind risers," so that the fluid metal of the feeder remains under the influence of atmospheric pressure long enough to force metal forward into the casting to replace liquid shrinkage and its tendency to form voids.

Normally, feeder heads are superimposed above the area of the casting to be fed and usually reach through to the top surface of the moulding box or feeder-head basin. The law of gravity is then allowed to function to force metal into the solidifying casting. To prevent early freezing of the head metal it is usual to cover the surface of the exposed metal with a refractory or a material yielding an exothermic reaction, or by plates placed across the feeder basin. It has not been properly realised, however, that with the covering of the head metal and its retention in the fluid condition over a prolonged period, the atmospheric pressure, which is equal to 14.7 lbs. per sq. in., has been acting on the surface of the fluid metal, tending to force it into any voids forming during the shrinkage of the metal of the casting, in addition to gravity. It must be clearly understood that atmospheric pressure cannot function after the formation of a solidified skin of metal completely around the feeder head.

It is usual to locate what are termed "blind risers" (feeder heads) on some part of a casting which cannot be reached by the usual feeders opening to the outside top of the moulding box. This enclosed type of feeder is known to vary in its efficiency. It is now clearer from the work of Taylor and Rominski why the action of "blind risers" varied. In the description of the methods adopted it will be noted that atmospheric pressure is conveyed to the most fluid and hottest zone of the "blind riser" (feeder) through the pores or interstices of the sand of the mould and an open-grained dry-sand core which communicates with the fluid interior of the "blind riser." The dry-sand core, which acts as the intermediary, is sharpened at the end, which is buried in the metal.

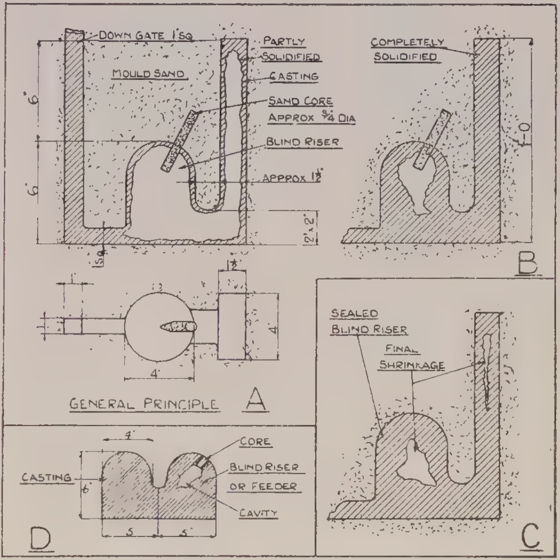

FIG. 3.—TAYLOR AND ROMINSKI METHOD OF BLIND-RISERING. A: Action of control obtained by atmospheric pressure—partial solidification is indicated. B: Complete solidification. C: Type of shrinkage experienced without atmospheric pressure control. D: Showing how the casting section on the left is fed, usually at the expense of the right-hand section which is used as a blind riser.

Fig. 3 shows a series of illustrations describing the work of Taylor and Rominski. Small modifications have been made by the writer to the original sketches by the American investigators. The modifications are made for greater clarity. The sectional elevation and plan shown at A, Fig. 3, illustrate, diagrammatically, the principle of "blind riser" feeding; partial solidification is indicated showing the probable heat gradients and freezing tendencies of the metal. The sketch B shows complete solidification and the probable shape and extent of the cavity. Thus, atmospheric pressure has enabled the feeding of metal to a point 6 in. above the height of the "blind riser." At C is disclosed the type of shrinkage which is experienced when the "blind riser" is cut off from atmospheric pressure by the early freezing of the first shell of metal in the "blind riser." D sketch shows how the casting on the left-hand side is fed soundly at the expense of the casting on the right-hand side.

The tests made by the writer, although not yet extensive, largely confirm the work of Taylor and Rominski. Its application appears most effective with metals of short freezing range, such as steel, malleable iron and certain classes of bronzes. The sand for phosphor bronze, however, must be carefully selected, otherwise severe penetration of the pores of the sand takes place and the "blind riser" becomes sealed.

It is obvious that, when harnessing atmospheric pressure in the manner suggested, it is equal to imposing a head height of from 50 to 55 in. in the ferrous alloys, brasses and bronzes and in other metals in proportion to their density. To superimpose such head heights above castings would be an expensive procedure, and in most cases difficult in the extreme. Yet, on the other hand, the new "blind riser" method compels the use of larger boxes in many cases, and in other instances the head metal and fettling are in excess of the standard methods.

Strength of Moulds to Resist Fluid Pressure

A reference to the photographs and sketches shown in Figs. 6 to 10 and the associated data on the stresses upon a mould emphasise the importance of providing suitable moulding tackle, and the fullest recognition of the effects of both the tackle and the work of constructing and consolidating a mould to withstand the stresses imposed by the fluid head of metal.

The effects of weak mould construction may influence the cost and quality of castings in a number of ways:—

(1) A complete failure to hold the metal in the mould means a loss of work equal to a casting minus the cost of dressing.

(2) Partial failure, such as a leakage of metal which is subsequently arrested and the mould finally poured may mean, if the casting is of any importance, that it may be rejected after having passed through important machining operations and tests. When a leakage occurs there is a strong tendency on the part of the caster to allow the head of metal in the pouring bush to sink, or he may make a complete arrest in the pouring operation to allow the leakage either to conjeal or to be stopped by emergency methods. Of course, in either case, dirt will probably have entered the area of the casting. Further, the arrest of the metal may allow partial

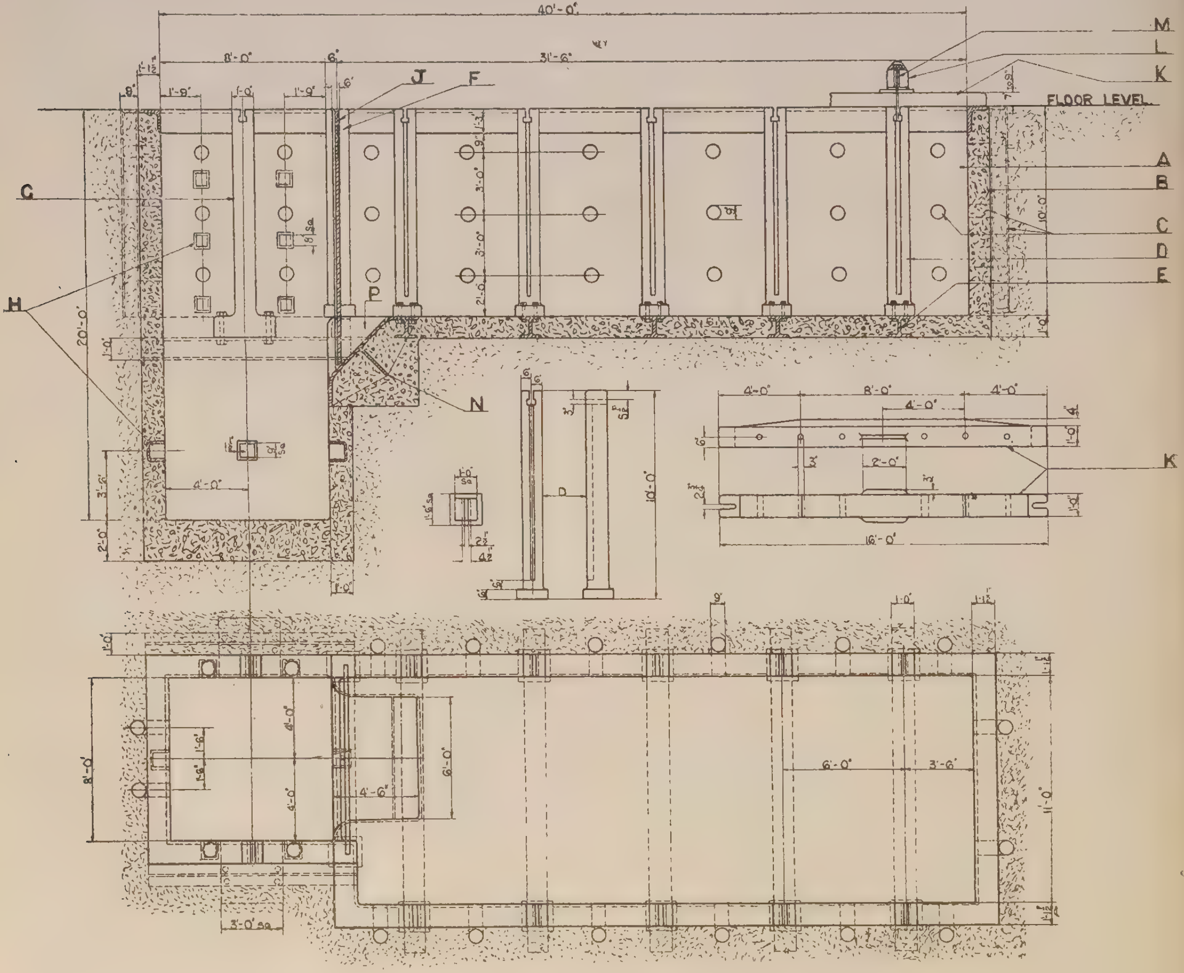

FIG. 4.—MOULDING AND POURING PIT.

solidification of the first metal admitted to the mould and when the secondary metal is passed into the mould, seams of imperfection can be noted at about the point where the upward flow of metal was arrested. If the flow of metal is arrested in such castings as liners or pistons one can anticipate a rejection. After machining a distinct line of dirt, blowholes and porous metal will be clearly seen at the point where the metal was arrested—even though the stoppage be only comparatively brief. After due considerations of the case, the casting should in most cases be rejected in the foundry and in the majority of cases without the slightest hesitation.

(3) The shape and scheduled weight of a casting are altered if a mould is strained. The stress imposed by the fluid head of metal will press into weakly rammed areas of a mould, it may be only local with its consequent disfigurement, or it may be general over the whole area of a mould, especially the bottom face of it. In the latter case a considerable increase in the section may result. A general or even local retreat of the sand face before the metal may prove disastrous. A core may have its print on the bottom face of the mould, and if the base of the mould is pressed down by the force of the metal the metal may pass under the core and into the core vents. This failure will probably occur just at the moment when the full head pressure is exerted, just when pouring ceases, and the core will have become bouyant.

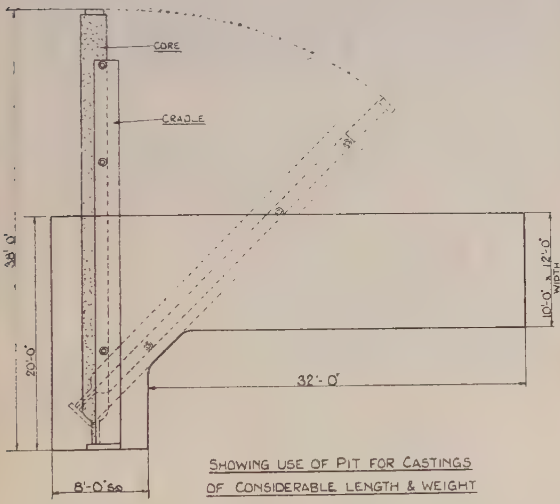
CORE
CRADLE
38'-0"
20'-0"
10'-0" x 12'-0"
WIDTH
32'-0"
8'-0" sq.
SHOWING USE OF PIT FOR CASTINGS
OF CONSIDERABLE LENGTH & WEIGHT

FIG. 5.—ARRANGEMENT FOR LONG AND HEAVY CASTINGS.

Camber allowances can be vitiated if the mould is strained because the extra metal is not allowed for in the considerations and calculations for camber allowances. The additional metal may create extra work and difficulty in the machine shops, especially when such castings are machined in jigs. The extra material machined off swollen surfaces will affect an increase in the exposed grain size and Brinell values of the metal.

Strength of Cores to Resist Fluid Pressure

It sometimes happens that a core fractures completely under fluid pressure, due to weak core reinforcements. It may be that the use of studs or chaplets is prohibited in a casting with a horizontal core of a comparatively lengthy nature and, if the core is weak, and other means of holding the core are not taken, the core bends, resulting in irregular sections. The failure of the core may be quite obvious or it may not be disclosed except by a distortion of the casting due to the uneven sections.

Metal may force its way through a softly rammed area of a core into the vent, and in the case of a loam core, through a too-thinly-applied loam coating around hay or straw lapping. It is not unknown for the loam thickness to be lifted bodily upwards by the metal because the straw or hay lapping has been incorrectly applied, or it has been charred by drying the core at too high a temperature. Loam cores placed in moulds poured on end, such as for hydraulic cylinders and ram castings, may fail, if not very soundly constructed. The high fluid pressure on the lower end of the core may squeeze in the core material. In such cases, the use of straw and hay lappings is omitted about the lower end of the core.

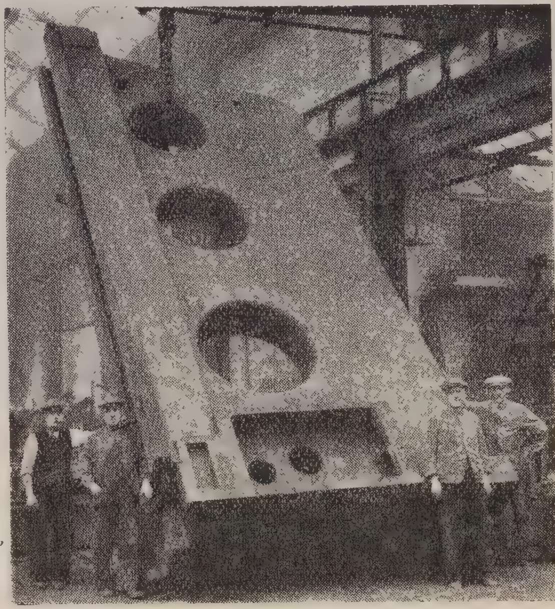

FIG. 6.—UPRIGHT MEMBER OF 17-FT. 6-IN. BY 60-FT. PLANING MACHINE, WEIGHING 26 TONS.

Casting Pits

Large castings of a few tons, up to 60 tons, are usually made in moulds constructed below the foundry floor line. With large castings it is necessary to explore well the strength of the pit. Brick, concrete or metal-lined pits are essential for safety with the deep, large castings. If, as is the case in many foundries, no specially constructed pits exist, a recognised good section of the floor is chosen. After excavating the sand pit, the moulder then examines the bottom and sides of the pit for weak soft places. It may be that he can strengthen a soft area by ramming, but often he is compelled to place loose plates in front of vulnerable or suspicious areas, behind which there may be a patch of free or soft sand. During his apprenticeship, the author remembers a very large casting being lost because of a weak area in the pit. The metal actually forced its way through 12 ft. of intervening floor into another pit.

Figs. 4 and 5 are sketches showing the construction of a pouring and moulding pit for a foundry engaged on mixed heavy work. It will be noted that the pit is intended to be of universal use to serve for castings made and cast in the floor or for the pouring operations only of moulds which have been built outside the casting pit. The pit is in effect a joint pit, consisting of, at one end, a deep section 8 ft. square and 20 ft. in depth, and extending into a large area 32 ft. by 12 ft. by 10 ft. in depth. The combined length of the pits is 40 ft. The details sketched in Fig. 4 are as follow:—A, the pit; B, concrete walls and floor; C, vent holes placed at intervals along the pit sides; D, cast-iron support and securing posts; E, steel I-beams to which E-supports are bolted; F, cast-iron support and securing post; G, cast-iron support and securing post; H, pockets in the sides of the pit to enable the use of additional securing tackle; J, cast-iron plates to divide the pit into sections (the plates locate in slots cast in the support posts, D, F and G); K, bolting-down beams; and M, bolts set in tee-slots in the posts D and G and through slots in the beam K.

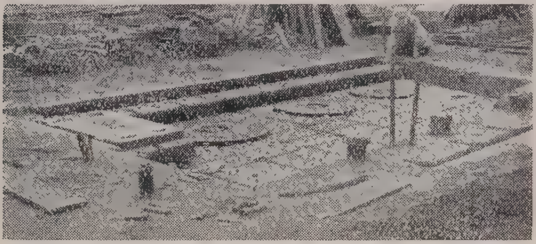

FIG. 7.—CORED MOULD FOR PLANING MACHINE UPRIGHT, SHOWING DISTRIBUTION OF CAST-IRON STUDS ABOVE THE CORES TO WITHSTAND FERRO-STATIC PRESSURE.

Moulds for a wide variety of castings can be accommodated in the universal pit shown in Fig. 4. including hydraulic cylinders and rams, boring bars, rollers, cylinders of various types, spindles, bedplates, etc. Fig. 5 shows diagrammatically the convenience of such a pit when making lengthy castings, which must be poured on end. Figs. 6 to 10 show examples of the types of castings for which strongly constructed pits are suitable. The pits must be free from all danger of water seeping in from the surrounding, perhaps water-logged, areas at X-depth from the surface.

The casting in the illustration (Fig. 6) shows an upright member of a large planing machine, its extreme dimensions being 23 ft. length, 10 ft. 6 in. width, and 4 ft. 3 in. at the greatest depth—at the foot of the casting. Not only must such castings be sound metallurgically, and because they are so much in view, they need to be free from those disfiguring local swellings referred to earlier, which are due to inefficient ramming. The obvious quality of the casting shown in Fig. 6 needs no comment; as to the craftsmanship it is necessary to put into the job a type of craftsmanship none too plentiful.

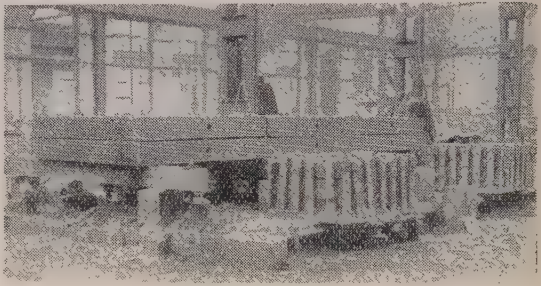

FIG. 8.—SHOWING MOULD ABOUT 18 HRS. AFTER POURING AND SECURED BY A COMBINATION OF BOLTING-DOWN TACKLE AND WEIGHTS.

Technical training will make a born craftsman a much better all-round foundryman, with still greater pride in the artistic side of his craft; but many

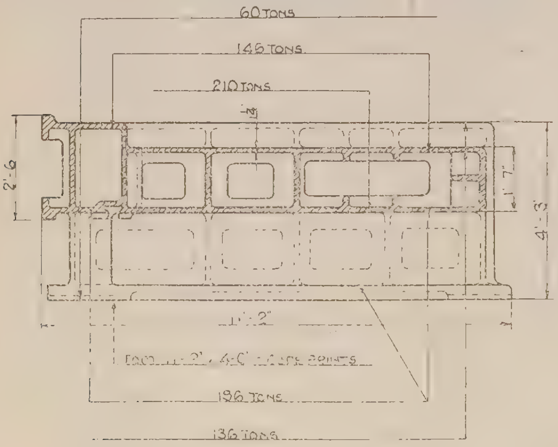

FIG. 9.—SECTION OF UPRIGHT MEMBER OF PLANING MACHINE. THE FLUID PRESSURE ON VARIOUS PARTS OF THE MOULD AND CORES IS INDICATED BY THE ARROWS.

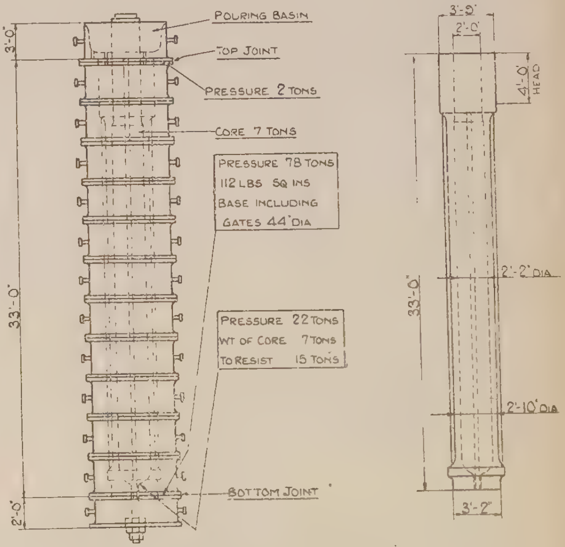

FIG. 10.—DIMENSIONS OF MOULD FOR A 20-TON HYDRAULIC CYLINDER.

foundrymen have lived long enough to realise that the technical training of a person without the natural attributes of a craftsman will, indeed, fall sadly short of the necessary qualities required to mould many classes of castings.

Distribution of Studs

Fig. 7 shows the wide distribution of studs over the face of the cores, the cores being surrounded by metal except for small gas outlets communicating between the cores and the outside of the mould. It will be noted that there are two sizes and types of cast-iron stud. The flat studs with the narrowed waist coincide with iron bearers built into and flush with the top face of the mould. The bearers are wedged under the moulding box bars during the building of the upper area of the mould. The smaller studs are slightly shallow of the thickness, so that when the mould is bolted down, or weighted, they will not penetrate the face of the top part and so disfigure it. The photograph (Fig. 6) shows how this practice succeeds. The smaller studs are located as an additional safeguard in preventing lifting generally, but they prevent local bending of the core and also pin down the surface of the core from which surface gases are issuing until the metal flows over it.

Fig. 8 shows the mould about 18 hrs. after pouring. It will be noted that the mould is secured by a combination of bolting-down tackle and weights. The casting weighs 20 tons. The lift on the top part moulding boxes is equal to the pressure exerted by the surface area in contact with the top box, plus the pressure from the lower face of the cores transmitted to the top through the intervention of the holding-down studs, minus the weight of the moulding box, cores, and the column of metal above the cores.

	Tons.	Tons.
The pressure exerted directly on the top is	136	
The pressure exerted under the cores and transmitted to the top through the studs is	196	
Gross pressure		332
Minus		
Pressure on the top of the cores ..	146	
Weight of top part moulding box ..	50	
Weight of cores	16	
		212
Net fluid pressure from liquid metal		120
Add 20 per cent. for momentum and gas pressure		24
Total pressure to be resisted		144

The sketches in Fig. 10 indicate the dimensions of a mould for a 20-ton hydraulic cylinder. In this case a very considerable pressure is concentrated on the bottom face of a mould of comparatively restricted area. The fluid pressure exerted at various points is as follows:—

	Tons.
Pressure on the bottom face of the mould, including the ring of ingates.. ..	78
Pressure on the underside of the core and on the top joint of the mould	24
Weight of core approximately	7
To be resisted a lift equal to	17 tons

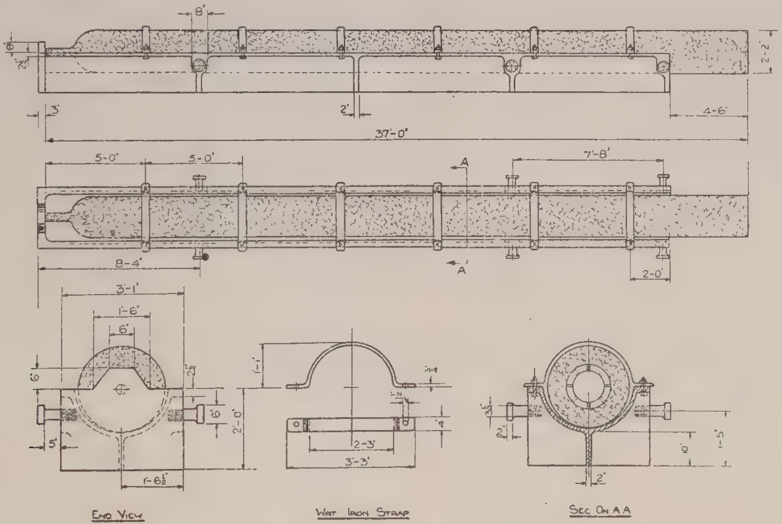

FIG. 11.—CRADLE FOR HANDLING LONG CORES.

The example of the hydraulic cylinder will serve to illustrate further the care needed when constructing lengthy cores to withstand fluid pressure. It will be noted that the sketches, Figs. 5 and 10, indicate that the core is made on a barrel, but that the mould is made in sections, the sections of mould being superimposed one upon another until the required length of casting is obtained.

So far as making the mould is concerned, the sectional moulding method is excellent, but difficulties are encountered in turning the core up to the vertical position in readiness to placing into the first sections of the mould located in a pit. The difficulties are that, although the core bar is 2-in. section, the core bends severely—it weighed approximately 7 tons. When the core is finally placed erect in the moulding pit, considerable repair is needed to the crinkled areas of the core started by the bending during handling by two cranes. Nor is the damage always obvious. Often areas which have been disturbed and weakened fail under the pressure of the metal and gas pressure inside the core itself.

Generally such castings as referred to are moulded horizontally when the core can be located horizontally in the bottom half of the mould being supported by temporary chaplets, which are withdrawn after the top box has been located and the mould turned up to the vertical position in a pit. Even so, the core must be soundly constructed, so that solid loam of a refractory nature is built up from the face of the core bar. If too much hay or straw lapping be used, the core surface will be compressed by the ferro-static pressure, especially about the lower areas of the cores. Actually no straw or hay lapping should be used for about 4 ft. from the lower end of the core as poured. And, wherever it is used, the lapping should not be continuous; spaces should be allowed for solid building of loam direct on to the barrel.

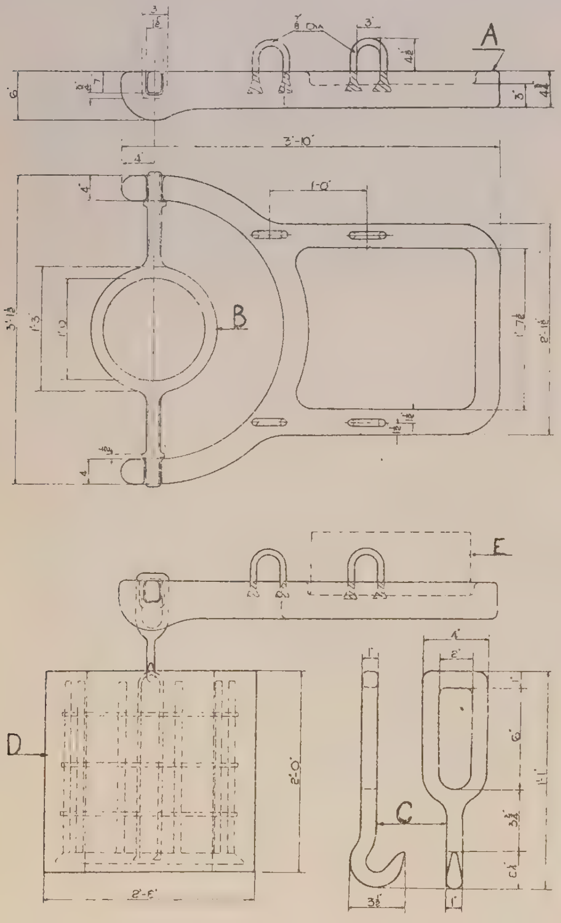

Fig. 12.—Core-handling Device.

Fig. 11 shows a cradle for handling cores of unusual length which the writer had made after core failure had been experienced. The cradle, of course, was only necessary when adopting the vertical-sectional-moulding method referred to. Of course, the core can be handled in other ways, such as passing a bar or bars through the section of core and barrel located so that, when turning the core to the vertical position, the core is more in balance.

In later years, the writer abandoned the production of large loam cores for such castings as described. The newer method devised was to make the core in sections and assemble the sections on a core barrel except the area of core forming the bottom end, which is strickled on to the barrel. When making the core in sections, the difficulty of lowering the sections over the core barrel was surmounted by the design of core balance shown in Fig. 12. The core-handling device is explained as follows:—A, the balance plate; B, core beam; C, core hook shackle; D, section of core; and E, loose weight to equal weight of core. Fig. 13 illustrates the use of the core-handling device in the assembly of a lengthy core as used for castings of the hydraulic cylinder class. It is self-explanatory.

Thus, the best moulding practice, that of making the mould in sections, is perfected by the sectional construction of the core, which is easily and safely made. When constructing the core sections, the hole formed in the centre of the core is made larger than the core barrel, leaving a space of about 2 in. between it and the core barrel. After aligning the section with the lower sections, the space is rammed with sand and cinders. It is unnecessary to use a hollow core bar. A solid core bar can be used if tubes are built up alongside it to carry away gases from the sand.

Cores made as described are an entire success, since a very suitable refractory sand can be employed, and it can be well consolidated. Squeezing in of the core face and penetration of the core surface by metal at a high head pressure is most readily avoided. From the core-handling device, Fig. 12, it is only another step to make a similar larger device for handling the section of mould. Assembly of mould and core sections is thus very straightforward and simple.

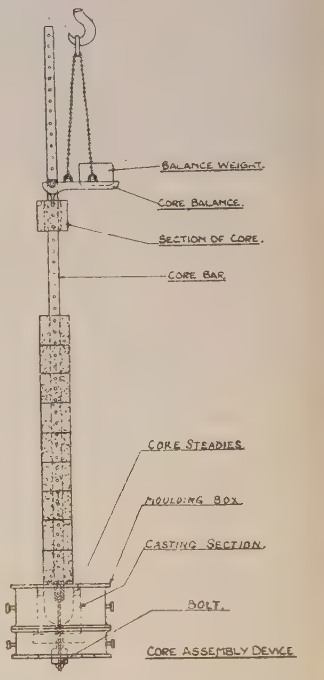

Fig. 13.—Use of Core-handling Device in Assembling a Long Core.

In conclusion, the author expresses his thanks to Craven Bros., Limited, and in particular to the chairman of the company, Mr. J. R. Greenwood, for granting certain facilities when preparing this Paper.

DISCUSSION

Mr. A. Hopwood, opening the discussion, said that by a coincidence he had just visited a foundry which was experiencing difficulty with test-bars, where a remark made by the foreman moulder was quite applicable to a viewpoint held by a number of foundrymen concerning the application of liquid pressure and risers. He then explained the point by means of a diagrammatic sketch on the blackboard, indicating that the method of casting the bars was effected by means of a simple down-runner. When the foreman was asked if he had considered putting the riser on the back side, namely, by putting an additional feeder on the back, his remark was that that reduced the pressure on the mould.

What was Mr. Longden's opinion concerning this point, because he (the speaker) considered it to be an error? The effect of putting a riser on any part of a casting would raise the pressure and carry the pressure to the same height, so that the down-runner did not release the pressure. He confirmed the statement as to the ill-effect of soft ramming, and there was nowadays a tendency for moulders to soft-ram. A perfectly sound mould could be obtained which, however hard-rammed, resulted in a perfectly flat face without scabs.

Use of Tying-down Bars

Another point he wished to raise was with respect to the screwing-down tackle, as it was called in the foundry, particularly with regard to large areas of, say, 18 ft. sq. or 18 ft. by 16 ft., or of that order. The distance between the tying-down bars and the holding-down tackle was very important. It should be borne in mind also that the fewer tying-down bars it was possible to use, the more quickly the job could be got together. The majority of such large jobs, when they had the top part on them, had to be screwed down—probably taking about 6 hrs. The more bars there were the faster it was necessary to work in order to get the job together. This was a technical factor which should be borne in mind.

Support must be given to Mr. Longden's contention with regard to using weight. It was found in the case of a serial job of what were called Diesel "A" frames, and which took up almost 16 ft. by 18 ft., that allowances had to be made for the straining of the top part. Screwing down could not entirely eliminate it. If the attempt was made entirely to do so with tackle, it would probably be found that bars would be required for every 5 or 6 ft. One could screw down a 16-ft. top bar with two tying-down bars, with the judicious use of weights at the corners and wedges in the appropriate places.

Test-Bar Technique

MR. LONGDEN agreed with Mr. Hopwood in respect to the test-bars. With two heavy sections connected by a lighter section, such as obtains in a test-bar, it is not quite possible to feed through the thinner section to the heavier section at the opposite end of the bar. The pressure depended not so much upon the number of headers or risers put on a casting, but rather on the head height and the time that the head metal would take to solidify. If the head could be kept open for a sufficient length of time in order to feed the heavy section, then the additional feeder, or additional riser, was not detrimental, but rather an additional insurance to feed the casting. It is unwise to pour a test-bar from two ends. Where the two streams of metal meet—in the important central area of the bar—there was every possibility of a collection of sullage and oxide films; hence the yield-strength will be lowered.

"Straining Downwards" and Lost Castings

MR. A. SUTCLIFFE recalled a member citing the case of a casting which had strained downwards—all castings strained downwards as well as upwards. The ramming had been done quite satisfactorily, but there was a sand bed beneath the excavation for the mould. The result was that there had been a straining into the sand bed and the metal had got away. In one case, when making blank wheels, a pressure of three or four tons had developed after casting. The noise of the blast which occurred was like that of a gun. In a second case a square condenser was being cast, but the metal percolated through the bed and was never found again.

Mould Explosions

MR. LONGDEN, following upon Mr. Sutcliffe's remarks and the incident of a gas explosion in a large blowing engine liner core, referred to during the lecture, said that at a certain moment, soon after pouring had developed, an explosive mixture of gases collected on the inside of the open core. It was the practice to place wood shavings on the inside of the core and light them a minute before pouring commenced in order that the products of combustion might take the place of most of the air in the large cavity of the core, and thus prevent a mixture of gases of an explosive nature during pouring. In the case referred to, something went wrong in the lighting of the shavings just before pouring commenced. Instead, it was left to a spark from the metal to drop into the core cavity and light the shavings just—as fate would ordain—at the worst moment, when an explosive mixture had formed from the gases given off the core and the air inside the core. The result was a shattering explosion, and much of the loam on the casting side of the core was projected into the mould cavity or the metal of the casting. This kind of thing occurs in a smaller way in many other types of moulds and cores, and they constitute unseen incidents of which the foundryman had no direct knowledge at the time they occurred. In the case of the hydraulic cylinder outlined, there was a tell-tale at the top end of the mould, about 1 ft. from the upper face of the head. When the metal issued from the "tell-tale" outlet, pouring was arrested until the hole was stopped with a clay bob. The remainder of the head area was then filled with metal.

Universal Plates

MR. LONGDEN, in answer to a question from Mr. A. Sutcliffe, said there was not the slightest doubt concerning the efficiency of the universal plates he had designed. It was perhaps unnecessary for him to state that if there were deep irregular lifts below the straight face of the joint line, probably the necessary combination was that of an ordinary soundly rammed top-part moulding box. But many types of lifts could be supported by cast-iron grids, rammed to the common flat surface and bolted to the universal top plate. When using the ordinary moulding boxes, many scores of lifters or grids and wedges and packing between the core face and the underside of the moulding box were needed. The universal top needed none of this attention. The surface of the plate was simply covered with an inch of loam in a matter of minutes, compared with days to ram the box parts. Ordinary loam plates were usually made for one-off jobs, or when the same type of casting was repeated at intervals. As a rule, they would suit only one or two classes of castings. But the universal plates were employed daily for a wide range of castings.

The universal plate was constructed of cast iron punctured with numerous cells to take care of venting and the gating system, as well as providing holes through which core bolts might be passed. They had been constructed in various ways; the best design consisted of what was really a composite plate. For instance, 12 ft. sq. top plates were made in three sections cast at the same time in the same mould. There was a central section, an inner frame surrounding the inner section. and an outer frame surrounding the inner frame. The sections were separated in the mould by 1 in. wide splitting cores. The sections were linked together by passing wrought irons diagonally through the splitting cores and into the metal on either side of the splitting cores. The object of all this was to take care of the expansions which take place. Plates will crack and fracture not merely through inherent casting stresses, but from repeated heating and cooling when subjected to casting operations. This remark applied especially to the central portion of the plate on which expansion was particularly rapid. If this expansion is not allowed for, then the plate will burst and fracture. That was what happened with the ordinary loam plates. The design of the universal plate took care of expansion, since the sections had the opportunity to expand individually.

The Double-flash Defect

MR. A. HOPWOOD asked if Mr. Longden had ever, in the case of a large surfaced casting, found a double surge showing on the flash. Although a job might be securely held down, this was particularly pronounced in the centre of the large top parts, where the spring was apt to show most, and not at the ends, which were securely held down.

MR. LONGDEN, agreeing, said it was very evident in a bed with camber; it was bowed down in the centre. In rising the metal flowed in and filled in the flash. Then, with the final and complete filling of the mould with metal, there was a secondary flash formed. This could be avoided by strengthening the mould and by adequate weighting or bolting down.

MR. W. BROWN agreed with the application of pressure or fluid feeding, because he was fortunate, or perhaps unfortunate, enough to serve his apprenticeship in a foundry which knew no risers. He was speaking more particularly of bronze than of iron founding. Bronze castings were produced up to 5 tons in weight. They never had anything more than a 2-in. down-runner, or 2- or 3-in. down-runners to spread the metal to the bottom. The height of the down-runner sometimes extended to 5, 6 and 7 ft. above the foremost portion of the casting. To sound a warning note, methods of moulding would have to be revolutionised. There should not be any attempt to cast any sort of casting with 5, 6 or 7 ft. head pressure unless precautions were taken at the bottom. Beds must be very carefully constructed, as Mr. Longden had pointed out, and the mould very securely rammed. The cores had to be treated in very much the same manner.

Modern foundry practice had laid too little stress upon fluid or pressure feeding, partly because, apparently, foundrymen were afraid to ram. There was no reason for such fear. A foundry with which he had been connected had been carrying out this practice for 60 or 70 years, only experiencing failure on very rare occasions. Castings had had to withstand as high as 3,000 or 4,000 lbs. pressure, and they had been successfully cast with high pressure and no risers. It should be emphasised that moulds must be carefully made before they could withstand such pressure. He dissented from Mr. Longden's remarks that pressure ceased to be exerted after the runner had set. Possibly this was so to a certain extent, but the pressure was being exerted while the runner or the down gates were being filled. It was at that part where the structure of the casting exhibited its weakness, rather than from a lack of atmospheric pressure after the casting had been filled.

MR. LONGDEN said there was certainly feeding taking place even when a skin was formed on the outside of the feeder, but it was then gravity feeding only. The work of Taylor and Rominski pointed this out very clearly, namely, that in addition to feeding by gravity there was the pressure of the atmosphere, equal to 14½ or 15 lbs. per sq. in. If some surface of the feeding metal area could be kept open to the pressure of the atmosphere, then it was atmospheric pressure plus gravity. More attention should be paid to the work of Taylor and Rominski.

Steam Pressure Feeding

MR. W. HOLLAND referred to the utilisation of steam. When visiting a Scottish firm, it was seen that, instead of rod feeding the jobs, they had steam-fed flywheels up to 15 tons. On the head of the runner boxes they put a loam-plate, with soft loam. Had Mr. Longden considered the question of steam pressure? If so, his experience would be interesting. In some foundries, with smaller boxes, instead of rod feeding they used a mixture of wet black sand.

MR. LONGDEN said he had made some experiments. He had mentioned the use of gases to aid feeding or, rather, for compressing metals, but that was done mechanically and in a very definite and controlled manner. Steam feeding was dependent upon the complete exclusion of the atmosphere, otherwise the steam would escape and the pressure of the steam lost. He was of opinion that much better results could be obtained by the atmospheric-pressure method. If the top portion of the head was covered with a refractory so that atmospheric pressure could continue to be exerted until the casting had solidified, then it was easier and as effective to impose the ordinary heads or feeders on castings. This object can be aided by introducing high-temperature metal to the feeder and then covering it with a refractory or a material giving an exothermic reaction.

MR. R. S. TURNER referred to the illustration of the upright casting. Would it be better if the cores were sprigged? Also, was the lift calculated? Taking off the weight of the box and various other things, there was about 125 tons, to which 20 per cent. was added. Should not the 20 per cent. be on the 300 tons and not on the 125 tons?

MR. LONGDEN said that, so far as sprigging was mentioned, he thought that Mr. Turner must be referring to moulds for small castings. The tremendous lift on the upright mould and its cores had to be very soundly resisted. The 20 per cent. allowance was a rough-and-ready calculation. He would agree to amend it by suggesting that the allowance could with added security be based on the gross amount, but the original basis was enough.

Atmospheric Feeding

MR. D. FLEMING referred to atmospheric feeding. He thought it was important that the core, which was inserted for the purpose of allowing the atmosphere to reach the centre of the blind riser, should have sharp edges, or have a section which would allow a break-through from the atmosphere to the centre. Some small experiments which had been carried out on the practical application of the method did indicate that this was not a matter to put aside and forget. It was really worth consideration.

The next point he wished to make did not really concern the subject-matter of Mr. Longden's Paper, but he would like to raise the question of test-bars. A point which must be now in mind was the condition of the second riser and the condition in which the metal was poured in. If the section was shown from the left-hand side, there was a temperature gradient to be taken into consideration, and there was a tendency of their being much colder metal on the right-hand side, so that the riser was not as effective as it might be made to appear. His practice was to cut out a thin section and cast the bars in ordinary D-section. They were run in and fed in at one end only, relying upon the temperature gradient, so that the hot metal was at the top and the coldest metal was furthest away. There was a danger of complicating the position by having two feeders.

MR. LONGDEN was pleased that Mr. Fleming had added this further point about the "blind riser." Although he had omitted to refer to the sharpening of the core, it was mentioned in the text of the Paper. He had missed it when departing from the reading of the Paper. The core needs to be sharpened so as to create the much-desired hot area or spot. The core, moreover, should be of a porous nature. If the test-bar was cast with one uniform section, it would be necessary to machine much metal off the bar; consequently a lower yield would be obtained from the test on the more open-grained metal of the inner zone of the original section. He would prefer to impose two feeders, but not to pour from two points, whereby there will be a meeting of two streams of metal and probable unsoundness there.

Aluminium as Flux

MR. W. COLLINGE made inquiries as to the use of fluxes for cast iron; he thought that Mr. Longden was a great believer in aluminium as a flux.

Suppose a 12-ft. cylinder had to be made about 24-in. outside diameter with 18-in. core. If the only barrel available was 10 in. dia., and it had to be built up, would Mr. Longden adopt the method which he (the speaker) used, namely, to build up about 3 ft. from the bottom with plates of about 6-in. section?

Referring to the illustration of the upright casting, Mr. Collinge said it was noticeable that it was run on the side, with all the studs on the thinnest section. The thick section was the other side. What was the object of this? Was it so that the metal coming into the thick section was not quite so hot? Was it to neutralise open grain, or to eliminate sponginess, or for some other reason?

MR. LONGDEN replied that the use of flux at the spout in the metal for heavy castings was not usually practised. There were inoculation methods whereby the quality of the metal was improved. Lectures had been given to the members of the Branch showing how metal could be improved by introducing certain elements which might be present in the original pig-iron, such as silicon, which, in a way, did act as a flux. But, with straightforward castings like the cylinder described it was just a strong cylinder iron, containing 0.9 per cent. silicon, 0.3 per cent. phosphorus, and about 3 per cent. carbon.

MR. COLLINGE asked whether the lecturer would advise the use of a flux on a thin section, say a 1-in. section, which had to be free from gasholes.

MR. LONGDEN said that since graphite was precipitated when introducing aluminium, it would increase fluidity by a certain small percentage. Even the fluidity decreased with a high percentage of aluminium. About an ounce was required to a ton of metal. He did not think Mr. Collinge would experience any difficulty with the 12-ft. casting, 24-in. dia. An ordinary loam core would be quite satisfactory if properly built up. The rope or hay band, however, should be properly separated on the core barrel itself. The position could be made much safer, however, by introducing the usual strengthening rods.

The comment about the running of the column was important. The runners were introduced into the mould at a point well away from the sliding surfaces of the casting. Actually it was fatal to run castings of that description in the heavy section, which happens to be the most important part of the casting. There was erosion of the sand, and especially so from big bodies of metal. It was his practice to run them well away from the important surfaces. Again, the surfaces were densened, and Mr. Collinge would be well advised not to let the metal impinge directly upon denseners.

Continuing, Mr. Longden said he had hoped, as a rounding off to the lecture, to be able to say something about studs, but there was not sufficient time left to show the slides. He had carried out some experiments. As was well known, there was a shortage of tin nowadays. When some materials other than tin were used, as well as tin itself, it was really astonishing to find that the only studs which really gave a sound section when cut across the stud and the parent metal were those which were simply ground clean or machined, such as threaded cast iron or steel. Other coatings showed a blown condition.

APPENDIX

During the discussion on the part played by metal studs to withstand solid and fluid pressures reference was made to unfinished tests carried out to ascertain the relative merits of various castings on ferrous studs against uncoated metal. Particulars of these tests are now appended by the author:—

Fig. 14 illustrates, diagrammatically, how the tests were made and some results.

The test consists of the location of studs in two cast-iron bars, 21 in. by 3 in. by 1 in., spaced at intervals of 3 in. The bars were notched at N to induce a fracture across the stud. The ingates, A, were placed to flow directly at the stem or central portion of the studs, in all cases. The ingates were fed by the two down-gates, B, of ample proportions to ensure equal pressure at each inlet point. Outlet gates were placed at the locations R, and since the studs were subjected to, as near as possible, the same temperature and quality of metal, conditions were similar for all types of studs.

The condition of the studs before inserting into the moulds were as follow:—

Coating.	Condition before Coating
1. Zinc	Bright clean metal surface.
2. Tin	,, ,, ,,
3. Copper	,, ,, ,,
4. Nickel	,, ,, ,,
6. Lead solder ..	,, ,, ,,

The nickel and copper coatings were electrically deposited.

5. Tin with coating as purchased.
7. Blue-black oxide film.
8. Smear of oil on the brightly-cleaned surface.
9. ,, ,, ,, ,, ,, ,,
10. ,, ,, ,, ,, ,, ,,
11. ,, ,, ,, ,, ,, ,,
12. Red lead on the stud and plates, without resorting to brightly cleaning the surfaces.

Three separate tests were made repeating the arrangements and conditions described above. In the first test the mould and gates were simply filled in the ordinary manner. In the second test an excess of about 1 cwt. of molten metal was allowed to flow through the riser gates. With the third test an excess of about 2 cwts. of metal was allowed to flow through the mould.

Fig. 14 illustrates, approximately, the condition of the studs in the third test. The blown condition around the studs can be attributed to, firstly, the burning-on of the studs and the gas from both the overheated stud and the coating. The blown condition was less pronounced in the second test, when 1 cwt. of excess metal had passed through the mould and still less pronounced in the first test when only sufficient metal was passed into the mould to fill it and the runner and riser gates. The blown condition was most pronounced in No. 12, and the rest of the blown areas in the following order as to degree of defect, starting with the most defective: No. 12, 7, 6, 5, 1, 2, 4, 3, 8.

The heavier studs, Nos. 9, 10 and 11, came out very satisfactory and no defects were encountered. The defect around the stud No. 8 was very small.

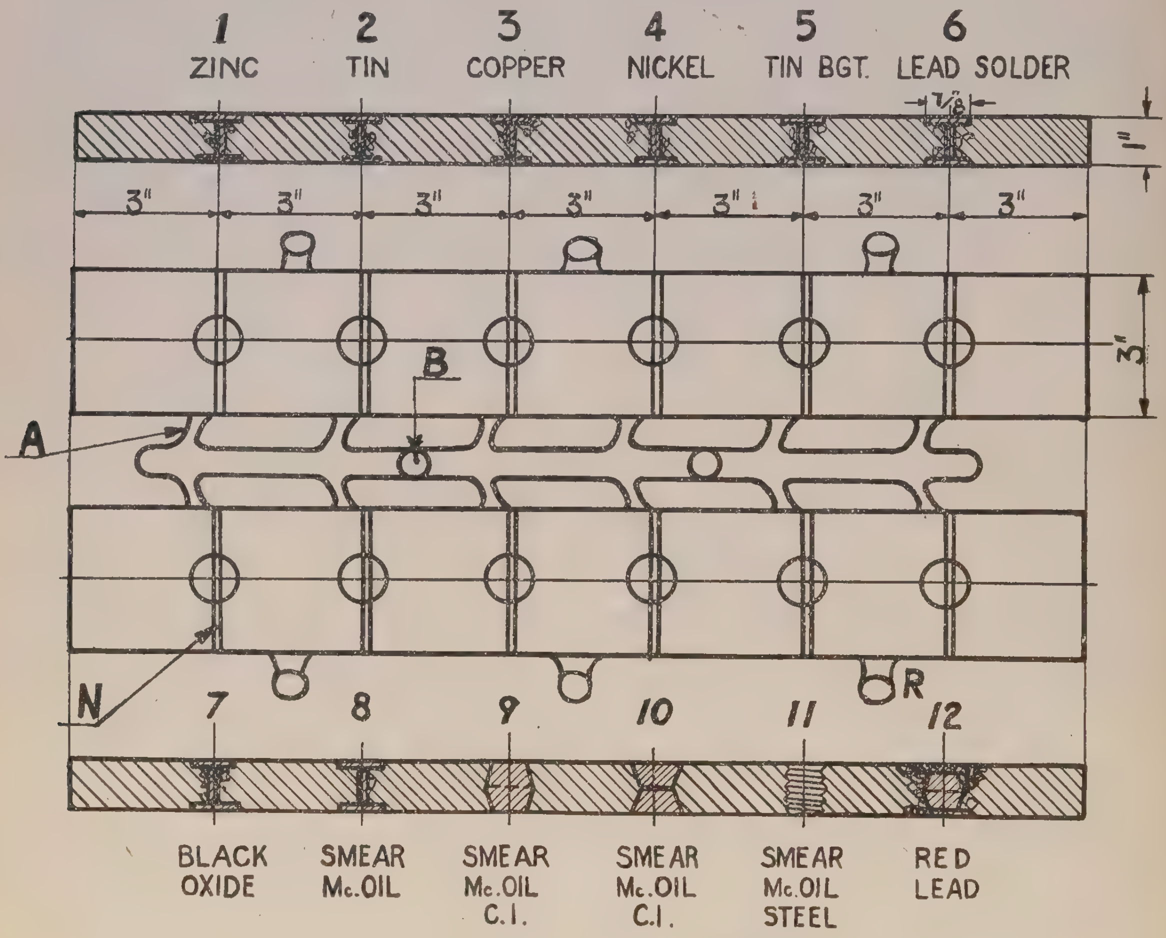
1
ZINC
2
TIN
3
COPPER
4
NICKEL
5
TIN BGT.
6
LEAD SOLDER
7/8"
1"
3"
3"
3"
3"
3"
3"
3"
3"
A
B
N
R
7
8
9
10
11
12
BLACK OXIDE
SMEAR Mc.OIL
SMEAR Mc.OIL C.I.
SMEAR Mc.OIL C.I.
SMEAR Mc.OIL STEEL
RED LEAD

FIG. 14.—DIAGRAMMATIC DETAILS OF PRESSURE TESTS.

The conclusions are that the best results can be obtained from perfectly clean, bright studs which are of such dimensions or located in the mould where they will not become too hot or approach the melting point. It would appear that the practice of tinning studs has grown up due to the need to protect the surface of the stud from oxidation and foreign matter from the time it is manufactured to the time it is used in the foundry.

London Branch **Paper No. 788**

Practical Economies in the Use of Corebinders

By A. TIPPER,* M.Sc.(Eng.) (Member)

The need for economy in the use of corebinding materials at the present time must be obvious to everyone. With a few exceptions all forms of vegetable drying and semi-drying oils, marine and fish oils, cereals and sugars, are needed for food or essential war purposes, whilst the bulk of them are imported from overseas. It is estimated that approximately 4,000 to 5,000 tons of such materials are used annually by foundries in this country for coremaking in normal circumstances, and probably considerably exceeded under present conditions. It is in the national interest to avoid waste or any unnecessary use of these valuable commodities.

Briefly it is suggested that economy can be achieved (1) by substituting natural bonded sand for oil sand: this is only practicable to a limited extent, and a number of objections to such a policy will occur to everyone; (2) by using lower proportions of corebinder than is normal practice: this calls for greater efficiency in general core making practice; (3) by more extensive use of permanent or semi-permanent cores: as, for example, in the light alloy and die casting industries, and (4) by the substitution of other materials as corebinders which may be in greater supply or of local origin (as, for example, by-products in extraction or refining processes), which could be used in place of imported materials.

Most of the following remarks will enlarge on methods of obtaining greatest efficiency in coremaking and obtaining maximum results from the materials in use, as well as suggesting possible alternatives. It is not intended to deal at any length with core sands, except to observe that the core sand is every bit as important as the binder in successful oil sand work.

General Survey of Materials Used

Before dealing with the various factors governing the efficient use of corebinders, it is as well to review briefly the characteristics of the materials which form the basis of the binders, core oils and compounds, since knowledge of the materials used is always a very great help in obtaining the best results from them. The individual materials in general use can be classified broadly into three groups, solids, viscous liquids and oils of various types (see Table I).

The principle solid binders include various types of dextrine and soluble starch produced from wheat, maize, potato, rice and tapioca starch by various chemical and heating processes. Dextrine has a normal moisture content of from 3 to 10 per cent., according to type and storage conditions, and picks up moisture from the atmosphere fairly readily. The mineral matter in dextrine is very small, but the solubility in water of different types varies considerably. Dextrine as a binder is very susceptible to small changes in moisture content of the sand, so that close control of moisture with all mixtures containing dextrine as a principal ingredient is essential. In the past, maize dextrine was most commonly used in this country, although potato dextrine and more recently tapioca, rice and wheat starches have all been used successfully where available. All these classes of material are of considerable food value, and the author believes that their use was largely discontinued in Germany well before this war, for economic reasons.

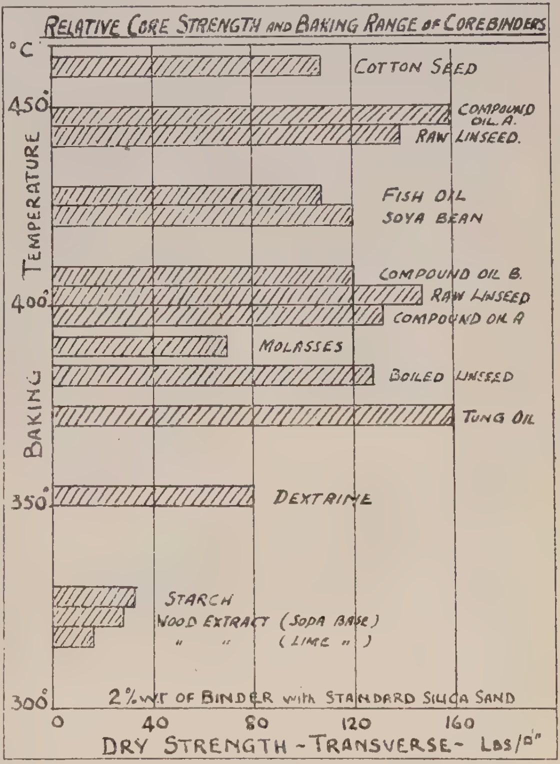

FIG. 1.—RELATIVE CORE STRENGTH AND BAKING RANGE OF COREBINDERS.

Corepowder

A different class of soluble starch, perhaps better known as corepowder, has come into prominence during the last 5 or 7 years. Produced largely from wheat starch which is treated to give a material with very high moisture absorption properties, it is not as soluble in the ordinary sense of the word as dextrine, but makes a very thick paste or jelly with cold water, and gives an appreciable green bond with undried silica sand containing, say, up to 4 per cent. moisture and not more than 2 per cent. by weight of corepowder. Small variations of moisture content do not affect the green bond of the mixed sand to the same extent as with dextrine, but in some foundries a proportion of dry silica sand is added to the undried sand to maintain the total moisture content of the mixed sand within certain limits.

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Neither dextrine nor starch imparts true moisture resistance to the dried core—*i.e.*, the core will soften under ordinary atmospheric conditions in the foundry by taking up moisture, and it is general practice to use a proportion of linseed oil, resin or other moisture-resisting agents in addition, if the core is to stand for any length of time and retain its strength. In general practice something like 2 per cent. by weight of dextrine or starch is usual, and it should not be necessary to exceed this figure, whilst the addition to this mixture of ½ per cent. by weight of good quality linseed oil will give excellent dry strength, using a clean silica sand.

Rosin and Pitch

Rosin and pitch are in many ways similar in their characteristics as corebinders. They impart only slight green strength with fair dry strength, but have excellent moisture resisting properties. Cores produced with these materials are very easily fettled, but mixing or distribution in sand is not easily accomplished unless the resin or pitch is dissolved in some carrying medium. Lime-treated rosin in finely powdered form, which does not adhere to form a solid mass on standing, is used in America for direct mixing in sand, and is now also available here. The most commonly used American type of wood resin is produced from shavings and pine roots by distillation. It is a bright reddish brown to yellow in colour, and is soluble in seed oils to the extent of about 25 to 27 per cent. This solubility is increased considerably by heating the oil, but on cooling and standing the rosin acids crystallise out, and only a limited amount will remain permanently in solution.

Gum rosins of many varieties are produced from various classes of tree, being the exuded sap or gum collected from the live tree, and imported from France, Spain and the Indies. These are of at least equal value to the distilled wood resin for core making, and in some cases being more soluble can be used in greater proportion. Pitch or bitumen are only partially soluble in oils, and require considerable heating, and the addition of

TABLE I.—*Classification of Materials Used as Corebinders.*

Class.	Name.	Type.	Characteristics.
Solids	Resin	Wood gum. Synthetic	V.G. Moisture resistance. Enhances dry strength value of thin oils—linseed, etc.
	Pitch	Mineral—petroleum coal Stearine.	Slight green strength. Dry strength with good moisture resistance when applied as solution.
	Dextrine	Maize Potato Tapioco, sago	Excellent green bond. Fairly good dry strength. Poor moisture resistance.
	Starch	Wheat, potato, rye	Good green bond, slight dry strength. Can be used with wet sand.
	Casein	Soluble or rennet	Little used. Good adhesive with air hardening and waterproofing properties.
	Sulphite lye	Soda base Lime ,,	Used mainly as green bond with oil sand or green and dry bond in weak sands. Water soluble.
	Mineral clays	Bentonites Colloidal clays Plastic fireclay	Replacing natural bond; also to impart strength at high temperature.
Viscous liquids	Molasses	First quality foundry type	Fairly good green bond. Good dry strength. Retards drying out of dextrine sand mixtures.
	Glucose	Water white or pale straw	Fairly good green bond. Good dry strength. Retards drying out of dextrine sand mixtures. Higher dry strength than molasses.
Liquids	Liquid resin	Water soluble thick resin oil	By-product. Low price. Fair bond and fairly good dry strength. Varies in character. Sticky.
	Sulphite lye	Conc.—1.30 sp. g. ,, —1.35 ,,	Similar to solid. Low baking temperature and readily burnt. Ash, 5—7 per cent.
	Rubber latex	—	Little use. Difficult to mix and unpleasant fumes.
Oils	Linseed	Raw oil Boiled oil	Highest dry strength. V.S. green bond. Good flowability. Air hardens on standing. Rapid baking.
	Soya	Raw oil; also Niger oil, etc.	Substitute for linseed. Does not bake as readily—no green bond. Very good dry strength.
	Fish oils	Herring. Seal. Red Oil. Cod.	Vary in character. Good dry strength and moisture resistance. Can be refined and deodorised for use in blended oils.
	Heavy fuel oil	0.85—0.96 sp. g. Petroleum base.	Requires high and prolonged stoving. Slight green bond is lost on heating. Good waterproofing. Used with linseed or other binders.
	Light mineral	Kerosene, spindle oil, etc.	Used as adulterant for seed oils and solvent for resin, etc

thinners to produce a reasonably fluid material. Because any green bond produced by such agents as resin and pitch is lost on heating the core, it is usual to add a proportion of natural bonded sand, or a clay or starch type binder to the mixture so as to produce sufficient stiffening of the core during baking.

Sulphite Lye

Powdered wood extract (or sulphite lye), as well as the concentrated liquid form, is available for use as a corebinder. It has a fair green strength, not as high as dextrine or starch with comparatively low dry strength, which varies somewhat according to type, the soda-base variety having a distinctly better dry-strength value than the lime-base type. The comparative dry-strength values of various corebinders, including wood extract, are set out in Fig. 1, which also indicates the approximate recommended baking temperature. The concentrated "lye" is used mainly for the improvement of moulding sands, and contains from 6 to 7 per cent. mineral ash. Its low baking temperature and cheapness are obvious reasons for its extended use as a corebinder.

Oils

Oils used as corebinders are listed in Table II, together with iodine values which, as well as indicating the drying power of the oil, give a good guide to the dry-strength value. Linseed oil is still the basis of most core oils. Both raw and boiled oil are used extensively, boiled oil particularly where its rapid drying properties are of service, though the raw oil gives distinctly higher dry strength. Linseed oil is one of the few materials in common use which will harden without artificial heating, and a mixture of silica sand with boiled linseed oil will toughen to produce a fair bond and plasticity on standing. Oils specially prepared with increased drying rates, such as the varnish or stand oils, will harden even faster, and a process of coremaking has been employed in some French steelfoundries using a mixture of hot silica sand, linseed oil and manganese dioxide. The large cores, after ramming up in the corebox, are left to self-harden and used without stoving.

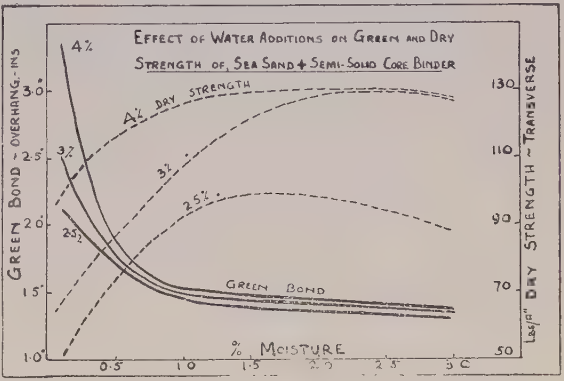

FIG. 2.—EFFECT OF WATER ADDITIONS ON GREEN AND DRY STRENGTH OF SEA SAND AND SEMI-SOLID COREBINDER.

Oils of the semi-drying oil class, used as substitutes for linseed oil, only oxidise and dry very slowly without the influence of heat. Some of the nut oils, soya bean oil and fish oils with low stearine content make good core oils, and all the principal oils tabulated will dissolve substances like rosin, pitch, bitumen and the metallic rosinate dryers, which are used to increase the drying rate

TABLE II.—*Oils Used as Corebinders.*

Type.	Name.	Iodine value.	Remarks.
Vegetable drying oils	Perilla	195—205	High price, resembles linseed.
	Linseed raw	175—195	Baltic variety has highest quality. Best-known core oil.
	,, boiled	140—170	Varies. Often adulterated. Rapid drying.
	Tung	160—170	Fastest drying oil known. Very high dry strength. High price.
	Soya bean	125—135	Substitute for linseed.
	Niger oil	130—140	,, ,, Not in common use.
Semi-drying	Corn or maize	115—125	By-product, in restricted use.
	Cotton seed	105—115	High baking temperature required. Fair dry strength.
	Ground nut	100—110	Adulterant for linseed, etc.
Non-drying and greases	Cocoanut	—	Gives slight green bond and a non-sticking mix.
	Resin oil	70—80	Seldom used alone. Cheap; some dry strength.
	Wool grease	—	Prevents stickiness and air drying in dextrine mixtures.
	Linseed grease	—	Cheap by-product. Low strength.
Fish oils	Menhaden	150—170	N. American fish oil. Good dry strength.
	Herring	120—170	Varies according to refinement.
	Cod, seal and liver oils	140—175	,, ,, ,, Good dry strength. Liable to contain stearines.
Mineral oils	Kerosene	Very small	Sp. G., 0.82. No dry strength. Solvent and adulterant.
	Spindle	,, ,,	Sp. G., 0.8—0.83. No dry strength. Solvent and adulterant.
	Fuel oil	,, ,,	Sp. G., 0.8—0.96. Seldom used alone. Dry strength. Fair and good moisture resistance.

and film strength. These oils will also form stable emulsions with other liquids and with water suspensions of dextrine, starch and other water-soluble binders, and the ease with which such mixtures can be emulsified has led to the common use of what are called core compounds (*i.e.*, mixtures of oil, water and some of the other bonding agents) which give a combination of properties. Each single bonding material has certain particular properties, such as high dry strength, or high green strength, or imparts flowability and ease of ramming, or rapid air hardening to produce self-supporting cores, etc., and by using certain combinations of the various binders it is possible to obtain a suitable oil-sand mixture to suit most requirements.

Paste Binders

The paste or semi-solid class of core compound consists principally of emulsified mixtures of dextrine, oil and water, sometimes with the addition of molasses or glucose in which the ratio of dextrine to oil is in the region of 4:1 and dextrine to water about 3:1. Such mixtures may also incorporate animal or vegetable fats as well as mixed oils, and produce a sand mixture possessing high green bond, the dextrine bond giving more or less self-supporting cores free from sagging or distortion when stripped from the corebox. The effect of moisture content of the sand on variation in green strength and dry strength of sand prepared with a semi-solid binder is shown in Fig. 2. Moisture resistance and dry strength of cores depend largely on the oil content of such binders, though, as shown in the curves, dry strength is improved by an increase in moisture content up to about 1½ per cent. The practical top limit of moisture content is dictated both by the green bond required and by working properties (*i.e.*, stickiness) of the mixed sands.

Core Creams

The cream type of binder is an intermediate stage between pastes and thin oils. They consist of emulsions of oil, water and dextrine, flour, molasses or bentonite in varying proportions. The solids seldom exceed one-third by weight and with a colloidal substance such as bentonite, or when emulsifying agents are used, the proportion of liquids (oil + water), may be as high as 95 per cent., though in dextrine mixtures it seldom exceeds 70 per cent. in order to obtain some degree of bond and air-hardening properties. The creams mix more readily with sand than the paste binders, and in general give higher dry strength with lower green strength. They are particularly suitable for larger cores requiring slow baking or any type of core which can be split and dried in halves on flat plates.

Thin oils of the linseed class have already been mentioned, together with certain alternatives in the semi-drying class of seed oils which require higher drying temperature and a longer drying time to produce their best dry strength. Seed oils may be adulterated with fish oil, rosin oil, non-drying oils or mineral oil to as much as 50 per cent., in order to obtain a cheaper oil, and some of these mixed oils give very satisfactory dry-strength results when used under suitable conditions. Mineral oil and paraffin are often used to increase the spreading power of the vegetable oil and act as solvents for rosins, gums, bitumen or pitch. Provided that baking conditions are suitably adjusted, these blended oils can be used in most mixtures in place of the pure seed oil.

In general, these core oils impart little or no green bond to a sand, and can only be used alone with silica sand where shell driers are used or for simple flat cores. At the same time, under carefully controlled conditions, very economical mixtures can be used as in certain cases known to the writer, where mixtures containing only 1 per cent. or less by weight of oil are in use. Although innumerable mixtures have been evolved in the past to give a certain combination of properties, including good green and dry strength with easy baking, absence of irritating fumes during casting or a core which will not go back in the mould, but yet will collapse readily after casting, there is still plenty of opportunity for investigation and improvement.

Fundamental Principles

Factors which govern the most effective use of bonding materials will now be considered.

Mixing and distribution of the binder in the sand: This is an important stage in producing satisfactory oil-sand cores which is still neglected in many foundries, where it is not appreciated that an intelligent operator should be employed on the mixing of oil sand. Many troubles with cores in the foundry can be traced to carelessness in sand preparation, lack of attention to mixers and rough methods of measuring the additions. All charges of sand and binder should be measured or weighed to a reasonable degree of accuracy with some simple apparatus, *i.e.*, measures to hold the right quantity of liquid binder or powder and bottom discharge hoppers to hold a charge of sand and mounted so as to empty direct into the mixer.

Mixing time and speed depend largely on the type of mixer, but the following points should be watched:—(*a*) Regular cleaning and adjustment of the mixer; (*b*) cold sand should be used, particularly with dextrine mixtures, and heating up of the sand during mixing avoided as far as possible, since both may lead to premature drying out of the mixed sand, with consequent wastage and friable edges to cores; and (*c*) hard pellets or lumps of binder in the mixed sand, which sometimes occur when using the paste or semi-solid type of binder, can often be traced to the formation of a hard crust on the surface of the barrel or drum of binder when left exposed to the air in a warm place. Binders of this type should be stored in a cool place and, when in use, covered with a damp sack or sprinkled with water to keep the surface soft.

Poorly mixed sand leads to poor cores, waste of coremakers' time and possibly blown castings. Attention to the above points, with provision of adequate supplies of dry cold sand and baking of cores within a reasonable time of making them will be found well worth while. With molasses or wood extract mixtures, it is sometimes convenient to prolong the mixing or raise the temperature of the sand by friction and so cause slight drying out of the binder with considerable improvement in green bond of the sand.

Naturally Bonded Sand

The use of naturally bonded sand may be advocated for two main reasons: (1) It produces green strength, therefore reducing the amount of starch or dextrine, etc., required to produce adequate bond; and (2) it produces a better finish on the core and resists metal penetration better than the straight silica sand core. Whilst increasing green bond, the addition of naturally bonded sand decreases dry strength for a given proportion of binder, and the amount of oil or binder required for a given dry strength must be increased appreciably (see Fig. 3). It also reduces the moisture resistance of the dried core as well as reducing permeability to some extent and in general the additions of naturally bonded sand should be kept to a minimum except in special cases—as, for example, in making cores for phosphor-bronze castings.

There is a very marked effect on dry strength when using additions of a fine red moulding sand such as Mansfield, but with particular mixtures (as, for example, when using molasses and linseed oil) the addition of 10 per cent. of naturally bonded sand gives a better finish to the core and less trouble in cleaning of the coreboxes on blowing machines. As an alternative to naturally bonded sand, bentonite, colbond, or fullers earth, can be used quite successfully to increase green strength without affecting permeability, provided that a suitable water addition is also made. Examples from practice of typical mixtures containing binding clay or natural sand additions are given in Table III. As to the supplies of silica sand, it is as well occasionally to test for silt or dirt content; loss on ignition and grading by sieve tests, and a sand containing gas-forming matter such as sea shell fragments, weed or sea coal should be avoided.

Use of Recovered Core Sand

For cores which require to be strong, permeable and to contain as little gas-forming matter as possible, the use of recovered core sand is not economical unless it is specially cleaned. Old core sand contains much of the unburnt or partially burnt binder clinging firmly to the sand grains, together with certain proportions of fines or clay bond if naturally bonded sand is used in the core mixture, and the use of even a moderate proportion of such sand with new silica sand will usually lead to: (1) Increased gas content of the cores; (2) lower permeability; and (3) a higher percentage addition of oil or binder to obtain the required dry strength.

Green bond is often improved slightly by the use of old core sand but this does not warrant its use except for additions to the moulding system or for unimportant block cores. There are numerous instances where cores can be used for less important jobs, such as backing up or outside cores in dry sand or oil sand moulds as used for cylinder block castings, and a number of foundries make use of the old core sand in this

TABLE III.—*Typical Core Mixtures Containing Clay or Clay Bonded Sand.*

Mix No.	Application.	Proportions.		
		Sand.	Binder.	Added water.
1	Alloy steel castings	400 lbs. Chelford Silica 3½ lbs. Bentonite.	7 lbs. dextrine. 5 pints linseed oil.	3—4 pints.
2	General steel castings.	330 Leighton Buzzard, medium. 70 York Yellow	14 lbs. paste compound.	½ pint.
3	High quality C.I. engineering castings.	360 lbs. Sea Sand. 40 lbs. Fine Red or Loam Sand.	5 lbs. dextrine. 4 pints thin oil. 3 lbs. molasses.	1—1½ pints.
4	Cast-iron gear box cores.	320 lbs. Undried Silica Sand. 80 lbs. Moist Red Sand.	8—9 lbs. core powder. 3 pints thin oil.	Varies.
5	Cylinder block moulds and cores, C.I.	400 lbs. Sea Sand. 2 lbs. Bentonite.	6 lbs. dextrine. 3 pints raw linseed oil.	2—3 pints.
6	Bronze valves and pressure fittings	220 lbs. Sea Sand. 100 lbs. Mansfield Red. 80 lbs. Ryarsh Silica.	5 lbs. corepowder. 5 pints raw linseed oil.	4—5 pints.
7	General brass and bronze (also core machines).	340 lbs. Sea Sand. 60 lbs. Moist Red Sand.	10 lbs. paste compound. 3 pints thin oil.	Trace.
8	General brass and bronze (also core machines). Higher permeability sand.	400 lbs. Chelford or Sea Sand. 4 lbs. Bentonite.	7 lbs. core gum. 3 pints linseed oil.	4 pints.

Unless otherwise stated, all silica sands in above mixtures are used dry.

way, milling it with a small addition of a cheap binder and water as required. These types of cores need not possess great strength and the addition of from 1 to 2 per cent. of molasses or wood extract, or about 1 per cent. of core gum should produce a workable mixture. In some cases mixtures of 100 per cent. recovered core sand are being used in this way, but the main problem of using recovered silica sand for general coremaking calls for a specially designed cleaning plant in which the sand grains are freed from bond before being re-used.

Two systems of cleaning are now being used to a considerable extent. The first employs wet methods of scrubbing the sand, which passes through a classifier, before being dried, and produces a sand in some respects cleaner and more regularly graded than the original sand received in the foundry. This process, which forms part of the Hydroblast system of hydraulic cleaning of castings,* is now applied very successfully in a number of steelfoundries in America, and it is understood that in consequence of the improved cleanliness of the treated sand, lower percentages of binder can be used than with the new sand as received by the foundry. The dry method of recovering core sand as used by certain foundries in this country makes use of a furnace to burn out all remaining binders, the sand then being passed over screens or suitable cooling trays fitted with dust extraction apparatus to remove all fines and ash, etc., from the sand. The relatively expensive plant required limits the application of such cleaning systems to foundries using large quantities of oil-sand cores.

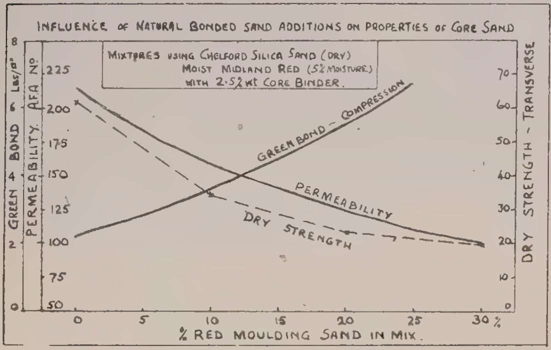

FIG. 3.—INFLUENCE OF NATURAL BONDED SAND ADDITIONS ON PROPERTIES OF CORE SAND.

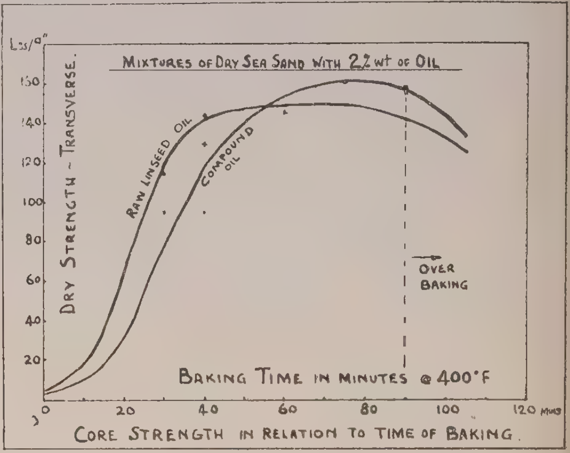

FIG. 4.—CORE STRENGTH IN RELATION TO TIME OF BAKING FOR MIXTURES OF DRY SEA SAND WITH 2 PER CENT. BY WEIGHT OF OIL.

Baking Practice

This is considered as the most critical stage in successful core production, since, ignoring the effect of the percentage of binder present and type of sand used, the degree of baking of any oil-sand core controls the mechanical strength of the core, its moisture resistance, and the volume of gas evolved when the core is used. The relationship between time of baking and core strength for two typical core oils used with sea sand is shown in Fig. 4. The baking temperature was maintained at 400 deg. F. ± 5 deg. for the whole period, and it is evident that the compounded oil requires a longer baking period or alternatively a

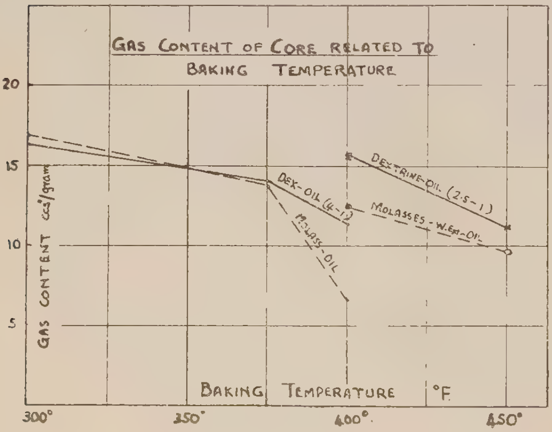

FIG. 5.—GAS CONTENT OF CORE RELATED TO BAKING TEMPERATURE.

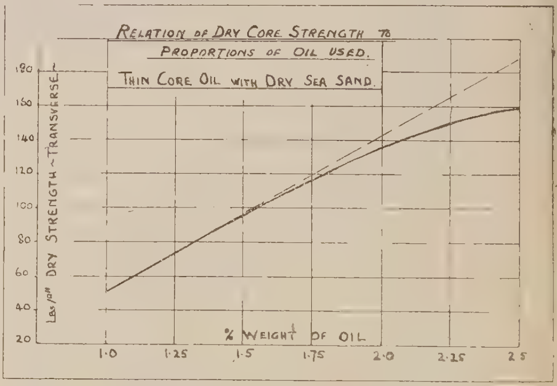

FIG. 6.—RELATION OF DRY CORE STRENGTH TO PROPORTIONS OF OIL USED.

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* "Foundry Trade Journal," February 19, 1942, pp. 117-120.

higher baking temperature than linseed oil. In actual practice this oil is normally baked at approximately 450 deg. F. Underbaking of cores results in low dry strength, poor moisture resistance and a high gas content, whilst overbaking gives weak friable cores but lowest gas content.

The influence of both time and temperature on the core strength and gas content of oil-bonded cores was very clearly shown in a series of curves included in a Paper by H. W. Dietert and F. Valtier on "Controlling Properties of Cores,"* to which interested readers are referred. Fig. 5 shows some of the authors' results contrasting molasses and dextrine under similar conditions of baking, proportions, etc. The correct baking temperature to use depends on the type of binder being used (see Fig. 1) and on the general stove conditions, whilst time of baking is largely a matter of bulk or section thickness of the core. As a rough guide, a baking time of 1 hr. per in. cross-section thickness of core is required for complete baking with sea sand cores. Much will, of course, depend on the shape of core, and the volume and heat capacity of the stove in relation to the load of cores, to be baked.

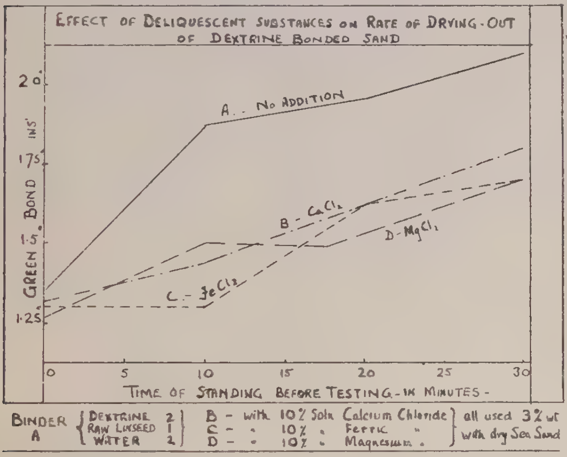

FIG. 7.—EFFECT OF DELIQUESCENT SUBSTANCES ON RATE OF DRYING-OUT OF DEXTRINE-BONDED SAND.

Other factors which tend to increase the time required for full baking of oil-sand cores are: (1) Sand of low permeability, *i.e.*, fine grained sand or sand containing appreciable fines, silt or clay; (2) a higher percentage of binder; (3) presence of non-drying oils, fuel oil, cotton seed oil, etc.; and (4) use of solid core plates or close packing of cores. For rapid baking there should be free access of hot air in the stove to all sides of the core, and movement of cores (as in a continuous drying stove) or circulation of the atmosphere inside the stove is a decided help in promoting uniformity and rapidity of baking. There should be a slight positive pressure inside the stove and if several stoves are connected to a common flue, they should be designed so that there is an equal pull on each stove.

The question of oxygen required for baking of oil sand is often mentioned and the necessity for supplying an adequate amount of oxygen is often rightly stressed. Determinations made by the writer of the oxygen required by one or two typical binders are given in Table IV, together with results of gas content determinations. It appears that, with the exception of the drying oils such as linseed, the amount of oxygen required is quite low. It is calculated that for a sand containing 2 per cent. by weight of raw linseed oil, 1 cub. ft. of core will require 56 cub. ft. of air at N.T.P. to supply the minimum amount of oxygen (provided no oxygen is lost or consumed in heating) consumed during complete baking, which is rarely accomplished in practice. Assuming a stove in which the load of cores occupies 1/5th the total volume, this means a minimum of 11 complete changes of air during the period of baking. With a paste type of binder only about one-third as much air is required and once the core attains the necessary temperature baking proceeds rapidly with evaporation of moisture and volatile constituents, such as light oil fractions, etc. Baking conditions

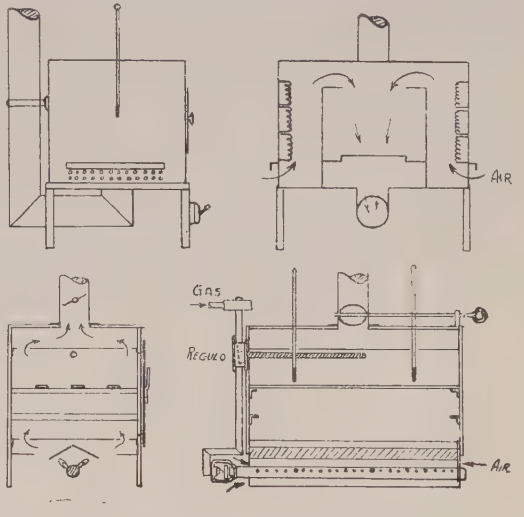

FIG. 8.—LABORATORY CORE-DRYING STOVES. (DESIGN A ABOVE; DESIGN B BELOW.)

TABLE IV.

Binder.	Gas content evolved at 800 deg. C., cms.³ per gram of core.	Oxygen required in baking, cms.³ per gram of core.
Concentrated wood extract ..	4.5	—
Molasses—R.L.O. mixture ..	7.4	—
D.-O.-W. cream	8.9	1.8
D.-O.-W. paste	11.4	2.35
Starch core powder	12.6	—
Raw linseed oil	14.5	7.5
Proportion of binder used ..	3 per cent. weight in each case.	2 per cent. weight in each case.

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* "The Foundry," April, 1933, p. 18.

must therefore be adjusted wherever possible to suit the type of binder being used, in order to obtain good results.

Dry-Strength and Gas Content

The dry-strength and gas content of a baked core increases in proportion to the amount of binder present up to a point at which the sand becomes saturated or completely coated with bond (see Fig. 6), when further increase in the proportion of binder is uneconomical from a strength viewpoint besides giving rise to increased gas formation on casting. Where baking conditions are unfavourable, an increase in the proportion of binder may also give little improvement in strength, but a dangerously heavy gas evolution in the mould.

Increased baking temperature results in a considerable decrease in gas content of the cores with practically all types of organic binders, and it is therefore good policy to use the highest temperature practicable, although care is necessary in the case of such binders as starch, dextrine and wood extract, which are susceptible to burning at temperatures over 370 to 400 deg. F. In drying small and medium sized cores there is often a considerable loss of stove efficiency due to door-opening for charging and discharging. This is overcome in modern stove design by: (1) The vertical continuous conveyor system; (2) a pusher-type carriage system; or (3) the tray or drawer type stove for small cores. A small continuous belt type oven using a wire mesh belt might well be used for mass production baking of small cores.

Storage of Dried Cores

In practice baked cores are never 100 per cent waterproof, they will always absorb moisture from the air under the usual atmospheric conditions in this country, with consequent softening and reduction in strength. The degree of waterproofing depends largely on the proportion of moisture resisting agents such as resin, pitch or oil used. Water-soluble binders give little or no protection and may even be hygroscopic, whilst the presence of naturally bonded sand reduces the effectiveness of oil additions to impart moisture resistance. Provision should therefore be made for storage of baked cores in a warm dry atmosphere. Alternatively they may be warmed up before use where they are kept in stock for any length of time after baking.

Control of Air Drying of Mixed Core Sand

Considerable wastage of mixed sand, particularly with dextrine-bonded sand, can occur through drying out on the bench, etc. The loss of moisture which results in the sand losing its plasticity can be retarded by: (1) The addition of deliquescent substances (usually chlorides or nitrites); (2) by increasing the humidity of the atmosphere in the coreshop; (3) by enclosing the mixed sand in containers, covering with damp sacking, etc.; and (4) by reducing the permeability of openness of the sand with additions of fine-grained sand, as in the case of mixtures containing a proportion of naturally bonded sand. The results of a series of comparative tests with chlorides of calcium, magnesium and iron are plotted in Fig. 7, using the same basic core mixture in each case. It will be seen that there is not a great deal of difference in the influence of these chemicals on the rate of drying out, which was measured by the increase in green strength of a rammed core on standing for various times before testing. A slight reduction in dry strength was experienced in these mixtures containing chlorides. In practice, continued use of such additions may have a cumulative effect in other directions, and for this reason must be used with discretion. At the same time the presence of some form of sugar, such as crude molasses or glucose appears to serve to a limited extent a similar purpose, in reducing the rate of air-hardening of dextrine bonded mixtures.

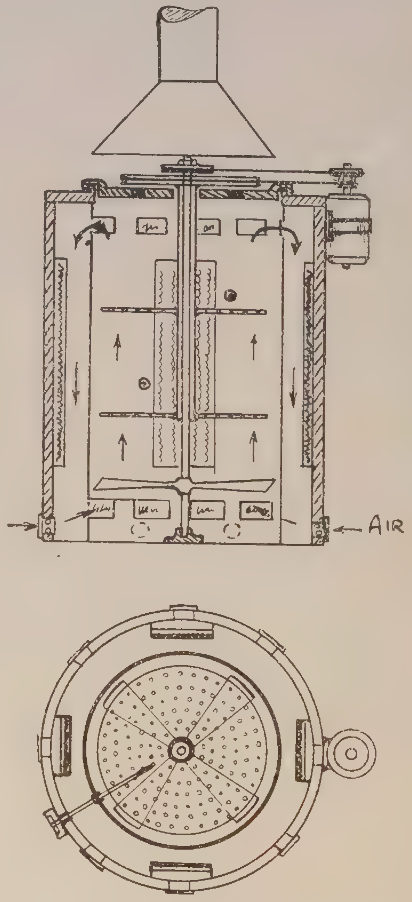

FIG. 9.—ROTATING SHELF-TYPE DRYING STOVE. (DESIGN C.)

Control and Testing of Corebinders

A brief classification of testing is set out in Table V, and may be divided into purely laboratory tests and those which may be carried out under more or less practical conditions in the foundry. Comprehensive information on the characteristics of seed oils, and methods of analysis will be found in the "Technical Handbook of Oils, Fats and Waxes," by Fryer and Weston, or in the "Chemical Technology and Analysis of Oils, Fats and Waxes," by Lewkowitsch and Warburton (3 vols.), to which students should refer. Tests on the corebinding materials by the laboratory will reveal any obvious variations in quality, excessive moisture content or mineral ash, and adulteration of seed oils, whilst routine tests on the prepared core sand will show variations in bonding value, green and dry strengths, etc. A series of oven tests will also give valuable information on the baking characteristics of any particular mixture and either the shop stove or a properly designed laboratory oven should be used. Figs. 8 and 9 show three types of laboratory drying stove; design A is that of Mr. W. Y. Buchanan, whilst design B has been used by the author with good results.

TABLE V.—*Testing Corebinders for Purity, Uniformity, and Comparative Value.*

CHEMICAL TESTS.	PHYSICAL TESTS.
Moisture content.	Stability and appearance.
Mineral ash, acid value.	Specific gravity.
Iodine value.	Viscosity.
Saponification value.	Flash or fire point.
Special identification tests.	

PRACTICAL CORE TESTS ON STANDARD SAND MIXTURES.

Green Bond.—Compression, overhang or shear.
Dry strength.—Tensile, transverse or compression.
Moisture resistance.—Effect on dry strength.
Gas content.—Influence of baking temperature and time.
Permeability.—Hardness.

For dry strength testing of oil sands, the author prefers the tensile or transverse test and the tensile test-piece can be conveniently rammed on the A.F.A. standard ram fitted with a suitable shaped head.* It is as well to standardise on some regular graded core sand for test mixtures, such as Southport sea sand, and so reduce the variables to a minimum. Practical tests on prepared sand mixtures give valuable information on the working characteristics of the sand and are of great help in determining the most economical proportions of binder which can be used.

As to the use of alternative materials, green bond may be obtained by the addition of a mineral clay, powdered wood extract, or a self-hardening compound such as silicon-ester or even waterglass, but the need for green bond can in many cases be removed by the use of suitable drying shells. In selecting a bonding clay, a type which has only moderate or low strength at high temperatures should be chosen. For dry strength, a simple thin oil-silica sand mixture may serve in which the proportion of oil can be as low as 1 per cent. by weight or less. The use of blended oil in place of pure linseed oil, using proportions of soya bean oil, nut oils, fish oils, and mineral oils containing resin, etc., helps to extend the available supplies of the drying oils, whilst residues from oil mills and refineries may be used with discretion where regularly available.

Conclusions

To summarise the outstanding factors in the best use of corebinders: Insure good mixing; use the cleanest and most regular sand possible; adopt regular and controlled baking conditions to suit the particular binders used; pay attention to storage conditions of cores; and carry out regular tests to secure uniformity of materials and consistent results in practice.

The author takes this opportunity of expressing his thanks to Mr. Morrogh, of the B.C.I.R.A., for his valuable assistance in preparation of slides, and to Mr. N. D. Ridsdale for the loan of lantern slides.

DISCUSSION

The BRANCH-PRESIDENT (Mr. R. B. Templeton), speaking on the practical side of foundry work, said that the conditions varied so widely as between different foundries, and the types of core that had to be made were so many, that the particular difficulties of one foundry were not those of another. The acid test of a core was that it should make a good casting. The second point about a core was its resistance to thermal shock, but the author had not touched on that subject, although he probably would have done had he had more time. Therefore, it seemed from the practical point of view that the conditions were totally different when a wide variety of cores was being made—large, small and medium in numbers, amounting to 500 or 600—from those in a foundry where small cores only were being made. For that reason it was essential to ensure that the core resisted the conditions in the mould, and having once established that fact, the mixtures used should be based on that knowledge within the limits found suitable, from that very important characteristic, *viz.*, resistance to thermal shock.

It was also most important that the core should maintain accurate dimensions. The green strength for handling was very important. Testing cores at high temperatures had not been carried out to any great extent yet in this country. An essential feature was that the core should stand up to the heat when the molten metal was poured against it. He specially stressed the importance of testing at the higher temperatures, because from practical tests it had been found that in the case of the lower tensile strength mixtures, say 70 lbs. per sq. in., the castings produced were dirty and, on increasing the tensile strength to, say, 140 lbs. per sq. in., the cores were difficult to remove from the castings and, in some cases, the castings were cracked. This emphasised the importance of control of core strength, and his view on the question of mixtures and various compounds was that the limits should be set by actual shop practice and experience.

Core Jointing with Fusible Metals

MR. V. C. FAULKNER (Past-President) said it was obvious from the Paper that any large-scale experimentation in the actual foundries was not worth while. In so much as the manufacturers of core mixtures and oils possessed large well-equipped laboratories, it was better to leave the conduct of such research to them, provided they continued their policy of publishing their results. The more the manufacturers gave to the foundrymen in this way, the less foundrymen would be inclined to experiment for themselves. A question of some importance was whether it was economical in wartime to join half-cores by pinning with fusible metal. He had seen that system in use in large motor-car factories, both at home and abroad. For the reclamation of cores there was a method of cascading the sand, air suction being used to remove silt. That was probably the most popular method in the larger foundries, but so far as the jobbing foundry was concerned, he did not think the reclamation of sand was worth while.

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* See "Foundry Trade Journal," January 21, 1937, p. 85-86, for illustrations and description of recent developments in Testing Oil Sands, by N. D. Ridsdale, F.I.C.

High Temperature Tests

The AUTHOR said he thought the Branch-President had given them a great deal to think about. He entirely agreed with his views that actual shop practice was the yardstick by which to measure the type of mixture to suit a particular job, and the laboratory or control test could come later. The thermal shock resistance and properties at high temperature of core mixtures had been investigated to a limited extent in this country and America, but he could not give any real guidance on this matter. This seemed to him to be one of the problems still to be dealt with.

MR. FAULKNER said that, although the Americans had carried out experiments at high temperatures, they found difficulty in deciding upon the best size of test-piece upon which to standardise.

The AUTHOR said he regarded tests at high temperature as fundamental, and research should be made on core mixtures at high temperatures. The point to bear in mind, however, was that the conditions in any experiment of this nature must duplicate practice. If a small core was tested at high temperature, it just burned away. Most core-making materials lost all their strength at temperatures in the region of 300 to 400 deg. C. He was not in a position to say anything about the jointing of cores. All he could say was that it was not in general use in this country, but he had seen the idea at Ford's works, and it might be copied if similar conditions applied, *i.e.*, making one core shell do double work by splitting the core in half and baking the bottom half in a shell, then putting the top half green on to the dried bottom half. This enabled a very high output to be obtained with a very lightly bonded sand. In the Ford case he believed the sand was rammed by Sandslinger.

Starch Sand

MR. F. GENTLES asked if the author had had any experience of starch sand. He had been associated with a firm which used this for a considerable number of years, and it was then quite cheap. It was obtained from a local firm, which was one of the largest cereal firms in the country, and was a residue from starch. This was boiled not in direct contact, but through the medium of water jackets, and mixed with the sand, which was used continuously over and over again for some 17 or 18 years, and very little new sand was bought. It had a good strength.

The AUTHOR replied that he had used mixtures containing flour, which would be somewhat similar to what Mr. Gentles had mentioned, except, of course, that Mr. Gentles was producing a soluble material by the boiling process. However, ordinary commercial flour had very little value as to dry strength. He asked if the mixture mentioned by Mr. Gentles was used for core making.

MR. GENTLES said yes, entirely. The cores were made up to a weight probably of three tons a day, and they had a very good test in as much as they went into bases, and were completely surrounded by metal. Afterwards the castings were rattled by being hit with a crowbar, and the cores easily collapsed.

The AUTHOR said this rather indicated the possibility of reducing some of the mixtures that were at present used to a rather simpler form. He imagined that Mr. Gentles was originally using a natural bonded sand.

MR. GENTLES said that was so.

The AUTHOR added that what Mr. Gentles had mentioned was rather like present day practice, in which natural bonded sand was used in the first place with the addition of wood extract or molasses or a little dextrine. In certain light alloy foundries this type of mixture was used, and the sand was used over and over again for years, and very little addition was made to it.

Core-Dusting

MR. A. BOWMAN asked whether the author knew of the practice of dusting cores with powdered rosin. He had done this in the case of light castings, and it gave a perfect skin. It was easily applied and must be put on hot.

The AUTHOR said he knew it was used in this country, but he had not had any practical experience of it. It was similar to the practice of spraying with a solution of rosin or pitch used in some foundries, but it was necessary to find a suitable solvent. There were foundries where solutions of pitch or rosin, and in some cases just diluted linseed oil, were sprayed on for more or less the same purpose as that mentioned, and also to increase the hardness of the skin of the core.

Waterglass Experiments

MR. W. THOMAS asked if the author had done any work with waterglass, *i.e.*, sodium silicate. On one occasion he had been trying to cut out the objectionable fumes given off by an oil, and tried the experiment of spraying with waterglass, but there had been the difficulty that the core did not break down very easily. Perhaps he had used too strong a solution.

The AUTHOR said he had used waterglass, and if sufficient was used to produce what he called a reasonable dry strength, then there was the difficulty that the core did not break down, and he had not found any method of overcoming that. In considering the use of alternative materials, he regarded sodium silicate as a possibility. For green strength, where it was necessary to cut down any gas-forming materials, there were possibilities in using a mineral clay of high bonding value and selecting a type which would break down (*i.e.*, one which had a low dry-strength at high temperature), such as the red clays or bentonite, or possibly using powdered wood extract, provided sufficient was available. The difficulties of using waterglass were obvious, and he also had found a great difficulty in producing a satisfactory mixture. It tended to harden and caked up the mixer, and he did not think it could be used satisfactorily alone. Oil did not mix well with it, and it did not form a very easily worked mixture on the bench. For dry-strength he suggested they should aim at economising as far as possible in the use of seed oil by adulteration or by using other materials in solution, or by making use of the pitches and petroleum products, and possibly synthetic resins, which gave a very satisfactory dry strength. Another aspect of the question of substitutes was the use of by-products, such as sooty oils, linseed grease, or other oil residues which could be obtained from oil mills.

Semi-Permanent Cores

A SPEAKER remarked that the author had mentioned the possible use of semi-permanent core materials, and inquired what material he had in mind.

The AUTHOR replied that he had plaster of paris in mind, but only for certain simple types of core, where stripping was obviously easy, something after the same manner in which a steel or iron core could be used. There were quite a number of wartime products for which sand cores used to be employed, but which were now made with permanent mould and cores, *i.e.*, steel cores, and stripping took place very early after setting of the metal.

Core Strength

MR. A. AUGSTEIN agreed with the author's statement that the green strength was improved by using a higher percentage of binder, but his experience had shown that the dry strength did not increase after about 2½ per cent. of binder had been used. Actually he had found that with 1.8 per cent. of a suitable binder, even cores which require a high dry strength (say radiator cores) gave satisfactory results; they had a silky surface, so that no infiltration of the metal into the cores occurred, and the high permeability was also kept and all other properties of a good core were retained. In many cases very high green strength is unnecessary, especially where core-drying shells are used. A core compound should not be based on a high amount of cereals. Apart from the saving point of this valuable food product, these compounds need in their manufacture a high percentage of water, which causes a great many difficulties during casting. He suggested that the cereal content of a binder should not exceed 20 to 25 per cent. Dry silica sand should be employed. Additions of clay or naturally bonded sand should be kept as low as possible, as they decrease the permeability. Finally, he thought the main aim of the coreshops should not only be to make cores easily, but to assist in the production of sound castings.

Red Clay Additions

MR. C. H. MERCER said he had tried liquid red clay, but it was not found possible to break down the clay sufficiently. Excellent cores were obtained, but they could not be knocked out easily. Could the author suggest some means of breaking down red clay sufficiently for this purpose?

The AUTHOR asked what percentage of red clay was used and what were the other ingredients.

MR. MERCER said the other ingredients were sea sand and linseed oil, and there were two-thirds clay.

The AUTHOR said there was bound to be this difficulty with red clay owing to its high dry strength. If the amount of clay could be reduced to about 10 per cent., as a maximum, there would be much more chance of success. It might be possible to introduce something which would break down at very low temperatures, such as sawdust or wood extract, something which would lose its dry strength completely at high temperature. Most clays had appreciable strength at high temperatures, and one could either reduce the amount of clay used or break the core up by introducing a substance which would burn out.

Vote of Thanks

MR. GENTLES moved that a hearty vote of thanks be accorded to the author for a lecture which was so very nicely balanced between the practical side and the theoretical side.

MR. A. BURGESS, in seconding, said that foundry foremen were rather inclined to buy the commercial products and not trouble much about what they were made of. He asked the author if he could indicate something that would increase the green-bond strength in winter. Calcium chloride had been mentioned as good for the summer, and he presumed it was added in the mill and not made an emulsion with the oil, but it would be useful to know of something that would increase the green strength of cream oil core compound which had been giving trouble during the cold weather.

The AUTHOR, replying, said there were one or two other materials he had not mentioned which might help Mr. Burgess. To retard air drying there was sodium nitrite, as advocated by Mr. J. J. Sheehan, which was very successful in retarding air hardening, but, as regards increasing the green strength in winter time, it depended very much on the mixture that was being used. Did the mixture Mr. Burgess was referring to lose its green strength on standing?

MR. BURGESS said it lost green strength when standing on a wet day.

The AUTHOR said that was rather unusual, and the mixture must be a very critical one. He could only suggest that, if natural bond was not being used, a little bentonite should be added to the mixture, as this had a very wide moisture range. One should also bear in mind the necessity for balancing the dry strength, because, whatever oil was present, had its efficiency reduced to some extent by the introduction of fine clay. That was the only suggestion he could make at the moment.

London Branch **Paper No. 789**

Fuel Conservation in Brass and Iron Foundries*

By FRANK HUDSON† (Member) and A. E. McRAE SMITH, M.A.† (Member)

A meeting, arranged by the Institute of Fuel, was held in London on July 17, 1942, when representatives of all the technical associations throughout the country were addressed by Major Gwilym Lloyd George, M.P., Minister of Fuel and Power. In his remarks, Major Lloyd George stated that he was of the opinion that considerable saving of fuel could be effected in industrial operations, and that it was not always practical to supply a particular type of fuel to meet special needs. He thought much of the modern plant and equipment used was inclined to be too selective in fuel requirements, and an effort should be made by industry to modify plant or method to meet the needs of the present supply position. The Minister of Fuel and Power went on to say that he needed all the help he could get from industry.

In this country to-day there are several thousand iron and brass foundries using large quantities of fuel and power, and it should not be difficult for each one of them to effect some measure of saving. The larger foundries with adequate technical control will no doubt have this matter already in hand, but unfortunately these are few in comparison with the number of small jobbing shops who, perhaps, would welcome a little guidance and advice on this most important matter. It is to the latter that the following remarks are principally addressed, although it is hoped that in reading this Paper the larger foundries may also gain some food for thought.

BRASS FOUNDRY MELTING FURNACES

Before commenting on any particular type of melting unit it might be useful to first of all compare general thermal efficiencies. F. W. Rowe has published the data shown in Tables I and II.

TABLE I.—*Furnace Thermal Efficiencies (F. W. Rowe)*[1]

Type of furnace.	Thermal efficiency. Per cent.
Coke-fired crucible pit furnace. Natural draft	3 to 7
Coke-fired crucible tilting furnace. Forced draft	8 to 13
Oil or gas-fired crucible tilting furnace ..	7 to 18
Reverberatory furnace	12 to 20
Cupola	30 to 40
Small electric furnace	40 to 65
Large electric furnace	60 to 85

C. L. Cassidy[3] and A. Logan[4] have also commented upon the fuel requirements of furnaces used in the brass foundry, and the latter author points out that in the case of the natural-draft pit fire, the coke to metal ratio is poor, ranging from 1:2½ (which can be regarded as good practice) to 1:1½ (which is often the ratio in practice). Taking an overall efficiency, however, of 1:2, the fuel required to melt a ton of gunmetal would be half a ton. With the forced-draft type of furnace the fuel ratio is 1:4½ and even in some cases 1:5. Taking the lower ratio, this would necessitate the use of 4.45 cwts. of coke to melt a ton of gunmetal. In the oil-fired crucible furnace, it takes approximately 28 galls. of oil to raise a ton of gunmetal to the correct pouring temperature. In the case of non-crucible furnaces, as the metal is heated more directly, the oil consumption is less, and can be taken as 22 galls. per ton of gunmetal melted.

Generally speaking, it can be concluded that to obtain the most economical fuel consumption in the more common brass-foundry melting operations, particularly as regards coke, it is essential to have plenty of air available for combustion. Accordingly every possible use should be made of forced draft and, when the type of alloy permits, direct fired non-crucible furnaces. A good air supply also provides greater latitude in regard to the type of coke required, as by suitable control of the air, soft or hard coke can be used according to available stocks.

TABLE II.—*Cost of Operating Various Types of Coke-Fired Furnaces (F. W. Rowe).*[2]

Operation.	Natural-draft crucible pit furnace	Forced-draft crucible tilting furnace	Half ton reverberatory (Sklenar type).
Total operating time (hours)	9.5	9.0	9.5
Charge weight (lbs.) ..	160	400	1,120
Melting time (hours) ..	1.5	1.75	1.25
Casting temperature (deg. C.)	1,200 to 1,250	1,200 to 1,250	1,225 to 1,275
Weight melted per day (lbs.)	960 (6 heats)	2,000 (5 heats)	5,600 (5 heats)
Fuel cost per ton (shillings)	17.5	16.0	12.0
Labour per ton (shillings)	18.5	18.0	11.0
Crucible cost per ton (shillings)	10.5	12.0	—
Electric power, repairs, etc., per ton (shillings)	2.0	2.5	3.0
Depreciation and interest (shillings) ..	1.25	2.0	3.0
Total cost (shillings)	49.75	50.5	29.0

Natural-Draft Coke-Fired Crucible Furnaces

Many furnace installations of this type suffer from lack of draft, and as well as having a very poor thermal efficiency can only be run successfully on supplies of soft coke. The obvious solution to both the above problems is to increase the air supply available as follows:—

(1) Clean out flues (many foundries are careless on this point).

(2) Prevent direct air leakage to chimney or stack by the use of well-fitting refractory furnace covers,*

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* This Paper, originally presented to the London Branch, was subsequently discussed by all branches.

† Mond Nickel Company, Limited.

* Iron covers waste fuel through heat losses due to radiation.

and, if necessary, increase area of air port inlet to fire bars.

(3) See that chimney or stack is in good repair (particularly if made of steel) and free from perforations near base. Check area and height of stack to ensure that it is capable of giving the draft required. Increase size of stack if possible or alternatively supply additional air required by the installation of a fan. If the latter method is adopted it may be necessary to enclose pit with steel plates so that a higher air pressure is created at the firebars than at the flue.

The installation of a draft gauge at the stack provides a useful measure of control. The application of auxiliary air by means of a fan should give a very elastic melting unit so far as coke requirements are concerned, as the stack should provide sufficient air for burning soft coke, whilst if harder fuel must be used the fan can be brought into use. If sufficient stack draft is available to handle the harder varieties of coke, the lower air supply required for soft coke can be obtained by reducing the size of the furnace exhaust flues by the insertion of loose firebricks.

Other points which should be kept in mind relative to the operation of all crucible pit-type furnaces in order to obtain maximum fuel economy are outlined below:—

(*a*) Keep lining in good repair and of correct diameter. Use template to check.

(*b*) Use correct size of crucible. Too small or too large a coke space is wasteful.

(*c*) Use correct size of coke.

(*d*) Keep air ports immediately above firebars clear of slag. Many foundrymen are of the opinion that the air supply should enter through the firebars. This is not good practice as the purpose of the coke bed on top of the firebars is primarily to support the crucible. The coke surrounding the crucible provides the heat for melting, and air should be supplied as shown in Fig. 1. Excessive burning of the coke bed which occurs when all the air enters through the firebars is wasteful.

(*e*) Run furnace to full capacity (*e.g.*, do not melt 50 lbs. of metal in a furnace designed to take 100-lb. crucible). Use a preheater top, made from an old crucible, and endeavour to get the whole charge of metal into the furnace at the start whenever possible.

Forced-Draft Coke-Fired Crucible Furnaces

Most of the comments previously made obviously also apply to forced-draft crucible furnaces. These units are primarily designed to work with the harder varieties of coke, and if any increase of melting time occurs over a period, it should be ascertained that the fan is delivering the required amount of air and that dampers are working satisfactorily. Many foundries make no effort to control the air supply by means of the dampers, with the result that the latter get jammed with sand, etc., in a partially opened position. Furthermore, indicating devices originally fitted to the dampers get damaged or lost, with the result that the furnacemen become completely befogged as to when the damper is open or shut. This condition is aggravated by the fact that few non-ferrous foundries enforce air control by means of blast or draft gauges. Maximum fuel efficiency cannot be obtained on forced draft furnaces without proper air control, and it is most important that dampers be maintained in good working order, together with clear indication as to the degree of damper opening. Final checking of the air supply should be done with the draft gauge. Such control will also facilitate satisfactory results being obtained with a wider variety of coke which is essential to meet the present supply position.

With forced-draft furnaces, lining wear is much more severe than when natural draft is employed, and it is therefore necessary to patch frequently so as to restore the diameter to the original size as fixed by the furnace manufacturer to give greatest efficiency.

Oil-Fired Crucible Furnaces

Rapid melting in an oxidising atmosphere provides the best conditions for the melting of the majority of non-ferrous alloys, and incidentally gives greatest fuel efficiency. This is not readily obtained from all furnaces, when the trouble will usually be found to be due to the fact that the burner or fan are too small to give complete combustion. In such cases, the remedy is to fit a larger burner and fan. The provision of an adequately sized burner and fan is of particular importance when handling high melting point metals, such as nickel alloys, etc., as large quantities of fuel are often wasted in an attempt to reach temperatures in excess of those for which the furnace has been economically designed. On an open-topped oil-fired crucible furnace a guide to melting conditions can readily be obtained from the colour of the exhaust flame, which should be of a transparent yellow with green edge bordering to yellowish-green. The depth of the greenish tints is roughly proportional to the amount of free oxygen present. A bright yellow or sooty flame denotes incomplete combustion and should be avoided.

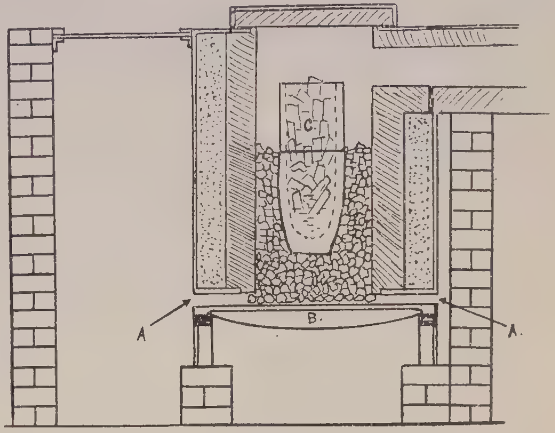


FIG. 1.—SECTION THROUGH NATURAL DRAFT CRUCIBLE FURNACE SHOWING ARRANGEMENT OF FIRE BARS AND AIR PORTS.

The cast-iron firebars B rest upon steel bearer bars and can be slid to one side for removal of clinker. Between the top of the firebars and the bottom of the lining there is a 2-in. gap A. The bulk of the air should enter the furnace through this port, very little coming through the firebars which are closely spaced. This confines the main combustion to the sides of the crucible where it is wanted and prevents the bed coke burning away too rapidly. It is also an advantage to have a deep furnace which will take the whole of the coke required for a heat at one time as well as a crucible fitted with preheater C. Frequent recharging of coke and metal wastes fuel.

A very common source of fuel wastage on oil-fired furnaces is caused by the burner being out of alignment with the combustion chamber, and trouble in this direction can be best avoided by frequent inspection. It is also important that carbon should be prevented from building-up in the combustion chamber, particularly when burning tar or pitch oil.

Larger foundries having the necessary metallurgical assistance available should make more use of exhaust gas analysis in checking fuel efficiencies. It should also be remembered that because a furnace uses more fuel per hr. (after modification has been made), it does not follow that this is being wasted. It may be that due to more complete combustion faster melting is being obtained, and the fuel consumption per pound of metal melted is actually less. Considerable quantities of both coke and oil can also be saved by properly organised melting practice. Even to-day, far too many foundries allow moulders to melt their own metal. This is entirely wrong as the metal is often allowed to remain in the furnace for a longer time than is necessary, which wastes fuel. Melting operations, even in the smallest foundries, should be under the supervision of a reliable man capable of developing the full productive capacity of the furnaces under his control. The elimination of quite minor points, such as shutting a furnace down during the meal hour or bad judgment in connection with molten metal temperatures will, in the aggregate, save fuel.

IRON FOUNDRY MELTING FURNACES

Since the cupola is still the most commonly used melting unit for the production of grey iron castings and accounts for over 90 per cent. of all iron castings produced, it is very important that attention should be given to fuel conservation in this type of furnace. As is the case in the brass foundry, the larger producing units will most likely have adequate technical control to ensure that melting is carried out under the most efficient and economical conditions. This is often not so in the majority of jobbing foundries, which account for a great proportion of the total tonnage of iron castings produced to-day, and the following hints on fuel consumption and conservation are given mainly with the object of assisting the smaller iron foundries. The remarks of course apply to cupolas of all capacities.

Amount of Coke Required for Furnace Bed

Unlike most furnaces the *weight* of coke in the cupola bed does not give a correct idea of its efficiency. The height of the bed above the tuyeres is the important factor, and therefore to maintain a constant height for a given weight of coke, the size of the individual pieces of coke is important. Hard cupola coke usually has a density of 25 to 30 lbs. per cub. ft. If really large pieces of coke are selected or reserved for the bed, then it is obvious that a smaller weight will be required for any given height of coke bed. This selection can easily be carried out by the cupola staff at odd moments, the smaller residual coke being reserved for the melting or "split" coke where a definite weight, as opposed to a definite volume of coke, is required, always provided a minimum thickness of coke layer is ensured in each "split." The ideal thickness of this layer is usually given as 6 in., and if the coke is comparatively small, this will mean a greater weight of coke per "split" to maintain this minimum thickness. In such cases, economy in fuel consumption is still possible, simply by increasing the weight of the metal charge to correspond with the weight of the coke "split."

In making the above recommendations with a view to fuel conservation, it is assumed that the cupola lining diameter throughout the well, melting zone and stack will be maintained as nearly constant as possible from day to day by adequate patching or daubing after each melt. When the lining at the melting zone is allowed to become even slightly larger than originally, particularly at the lower end of this zone, a very considerable wastage of fuel in the bed will occur.

It is not recommended that the actual height of the coke bed should be lowered with a view to saving fuel. This would be a false economy and lead to dull metal and loss of man-hours from resulting scrap castings. The first essential in producing good iron castings is to have metal of a sufficiently high temperature. The actual height of the coke bed in any cupola will depend on the type of metal being melted. For ordinary phosphoric cast iron without steel scrap in the charge, it will vary between 24 in. and 30 in. above the centre line of the tuyeres, but for high steel scrap charges and high duty cast irons in general, it must be increased to 36 in. or 48 in., particularly where it is essential that the first metal to be tapped shall be at a high temperature.

Melting Coke Charges or Coke "Splits"

Where melting has to be carried out without adequate control a great deal of coke may be wasted by the use of too large a "split" of coke. The actual melting ratio will depend on the type of metal being melted, and will normally vary from 7 to 1 (*i.e.*, 7 parts of metal to 1 part of coke by weight) to 12 to 1, or even 14 to 1. The greater amount of coke is required when melting high steel scrap, in order to allow for carbon absorption by the steel.

A very good guide for the jobbing foundry as well as for the large repetition foundry is to check up on melting rate. A figure sometimes quoted for normal or average conditions is a melting rate of 20 lbs. of iron per min. per sq. ft. of cupola area at the melting zone. This is equal to 1,200 lbs. or approximately 0.54 tons per hr. This figure is much too low, and the ideal to be aimed at should be at least 28 lbs. per min., equal to 1,680 lbs. or 0.75 tons per hr. per sq. ft. of cupola area. In actual practice, a melting rate about midway between these figures may be considered fairly satisfactory for small blows, but under the best conditions, the higher figure of 0.75 tons per hr. may be exceeded.

If the melting rate in any cupola be found to be less than this, and particularly if the metal is dull, then the weight of the coke "split" should be reduced progressively until a satisfactory melting rate is obtained, coupled with metal tapped at an adequate temperature. Much cupola coke could be saved in this way.

General Hints on Fuel Economy in Cupola Melting

(*a*) The amount of any individual melt should be as large as possible. Small short "blows" should be avoided by regulating moulding operations to suit the melting programme.

(*b*) The cupola should be prepared early in the day, the bed made incandescent as soon as possible and on completion of charging, as long a period as possible should be allowed for soaking the charges to ensure maximum preheating of the initial metal.

(*c*) During melting, the cupola should always be kept full to the level of the charging door.

(*d*) All coke and metal charges should be accurately weighed. Measuring coke by volume (except for the bed coke) is unsatisfactory and often highly wasteful.

(*e*) Adequate steps should be taken to recover as much of the residual bed coke as possible at the end of each "blow." After quenching, the coke should be carefully and thoroughly separated from slag, etc. This coke should be mixed wtih fresh coke and the mixture used towards the latter part of the next day's blow. On no account should it be used for core stove and other types of heating, where softer grades of coke are normally satisfactory.

(*f*) Excessive poking of tuyeres to free them from frozen slag should be discouraged. This leads to loss of efficiency. If it is necessary to clear such slag accumulations in front of tuyeres, then each tuyere should be closed for a few minutes in rotation. This will melt the frozen slag. In the same way, slag holes should be closed up after each slagging operation, and not be left open continuously during the melt.

LADLE HEATING

Many foundries build a coal or coke fire in ladles for re-heating purposes. Large amounts of fuel are consumed in this direction to little purpose. A small fire may be quite useful in drying out a ladle after relining, but this method is not economical for preheating preparatory to filling with molten metal. For the latter operation properly designed preheating equipment, fired by gas or oil, is indicated. If such is not available use a small fire to ensure that the ladle is dry, tap the metal at a slightly higher temperature, or pour the larger castings first when a drop in temperature caused by the use of cold ladles is of little moment.

In some foundries where it is still essential to dry and heat ladles by means of solid fuel, some considerable saving of coke, etc., can be achieved by the use of waste wood. There is often considerable accumulation of very small waste wood available from the foundry patternshop, which is of little value except for furnace lighting and ladle heating.

MOULD AND CORE DRYING

There are still far too many foundry drying stoves operated by open fires, and such methods are highly wasteful of fuel. The most economical method for drying moulds and cores with low-temperature processes is by convection heating, and this forms the basis of modern practice.

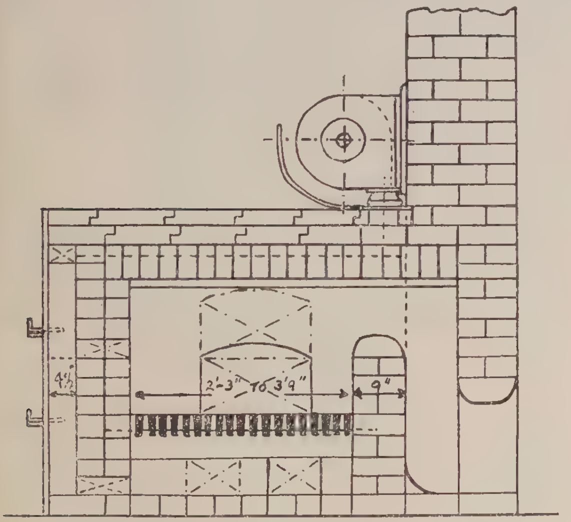
W. H. Smith[5] states that fuel consumption with forced-draft furnaces, in relation to the weight of moulds dried, varies according to the size of stoves and conditions of working, but under favourable circumstances 40 lbs. of sand can be dried per lb. of coke consumed. In one instance, 46 lbs. of sand per lb. of coke has been recorded. These figures may be a little on the high side. American data[6] published in the FOUNDRY TRADE JOURNAL is reproduced in Table III.

TABLE III.—*Weight of Moulds or Cores Dried Compared with a Given Unit of Fuel Consumption.*

Unit of fuel consumption.	Weight of moulds dried in lbs.	
	Ratio of sand to iron 1 : 1.	Ratio of sand to iron 1 : 2.
Electricity, per kwh.	10 to 15	8 to 10
Gas of 530 B.Th.U. per cu. ft.	1 to 2	0.75 to 1.5
Fuel oil per gall.	400 to 600	300 to 500
Coke per lb.	25 to 40	15 to 25

Naturally, the overall results are affected by a variety of factors, such as weight, shape and section of the mould or cores, kind of sand and matters related to the design and operation of the stove itself.

It is not practical to advocate the installation of new stoves at this time, but it is perfectly feasible for those foundries using antiquated drying methods to make certain modifications to existing practice or equipment in order to reduce the quantity of fuel em-



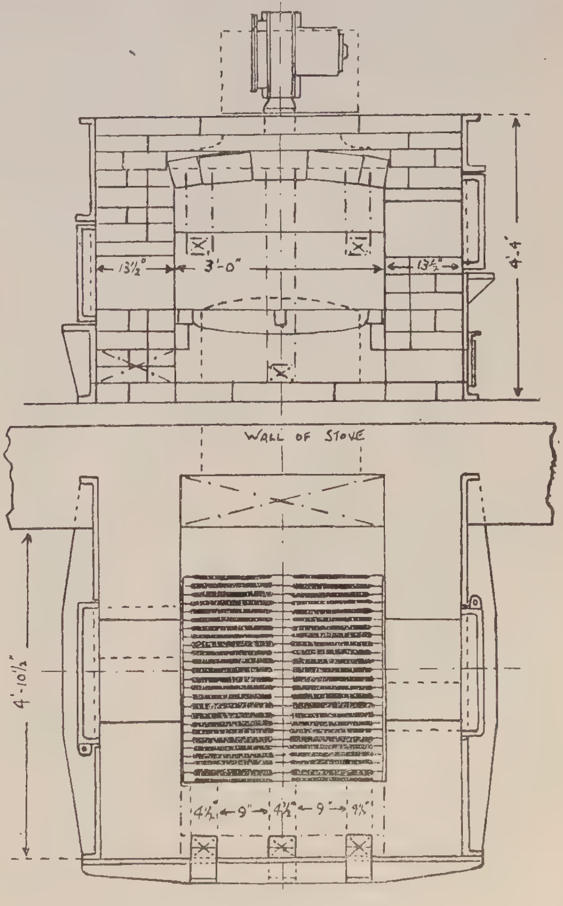


FIG. 2.—HOT AIR FIREBOX FOR FOUNDRY DRYING STOVES.

Firebox suitable for a stove having 3,500-4,500 cub. ft. capacity. Size of firegrate, 3 ft. by 3 ft. Air supplied by 5-in. dia. fan delivering 400 to 500 cub. ft. of air per min. at about 1 to 1½ in. water gauge. (Courtesy of Glenfield & Kennedy, Limited.)

ployed. Consideration should be given to the following points:—

(1) Fit a firebox which will circulate hot air in conjunction with suitable inlet and outlet flues for evenly circulating the heat and removing the products of the drying operation. A suitable firebox of the type shown in Fig. 2 can be readily constructed by most foundries.

(2) Use one firebox to two stoves and institute proper drying schedules, *e.g.*, whilst one stove is being fired the other is being loaded up. (Do not allow moulders to open up a hot stove frequently in order to put in or take out moulds or cores.)

(3) Fit a recording pyrometer so that a check can be kept on temperature and operation.

(4) See that each stove is well filled.

(5) See that doors and walls, etc., are properly insulated.

Open fires or braziers should not be used for drying moulds in the floor. Purchase a modern portable mould drier or make one along similar lines to that shown in Fig. 2. It is to be regretted that far too much use is still made of fire "kettles" and similar appliances for drying large moulds.

As already indicated, it is not practical to recommend the installation of new stoves at this time for the purpose of saving fuel, or even to carry out major alterations and improvements to existing plant. In some cases, however, it would be very easy and practicable to instal some type of automatic feed stoker, using very small coal and other types of fuel not in demand for general purposes. Attention to this should be given, in particular where stoves are still fired by open fireboxes.

Another small point with regard to the drying of cores concerns the use of excessive moisture in wet loam, particularly in cores which have been swept up. Fuel is required to evaporate the whole of the water in such cores, and although very wet loam sometimes makes it easier for the coremaker to carry out delicate operations in the production of the core, this can be grossly overdone. It would be interesting to check up on the amount of fuel used in foundries in Great Britain purely for evaporating this excessive and altogether unnecessary additional moisture.

USE OF COKE IN THE PRODUCTION OF LARGE CORES AND MOULDS

Although it is recognised practice to use only coke ashes and similar material for the centres of large loam cores as well as general venting purposes in cores and core assemblies, undoubtedly a great deal of good soft coke of usable size is employed in this way. Theoretically, all this coke should be recovered during the fettling of the castings or, in the case of ash beds for large moulds, the coke would be recovered each time the bed is reconstructed. In actual practice, this is not the case, and if any iron foundry cared to make a careful record of the coke used against the coke recovered in these processes, they would be somewhat alarmed at the actual fuel wastage. Even for a very small foundry, it is no exaggeration to say that this may reach a figure of 40 to 50 tons of coke per year.

Every foundry manager should use his ingenuity to prevent the use of raw coke for these applications, and in the case of very large loam cores, the centres are often filled completely with raw coke. These spaces can, in most cases, be left quite open. Where crushed raw coke is to be used for filling vent tracks, etc., porous material like blown crushed slag might be suggested as an alternative.

Finally, where no other substitute can be found and it is considered really necessary to use raw coke, very definite instructions should be given that this is recovered completely and subsequently used as fuel.

GENERAL

Electric power consumed for lighting purposes is a large item in these days, and admittedly it is difficult to utilise daylight as so many foundries have fitted permanent blackout. It might, however, be possible to save some electric power if occasional attention were given to the fitting or cleaning of reflectors. Very few foundries pay attention to this point, and allow lamps and reflectors to become covered with dust and grime so that a 500-watt bulb gives the light of 400 watt. Try considering the possibility of utilising lower-powered lamps fitted with reflectors and keep them clean. The results may be surprising both as regards the amount of light obtained and electric power saved. Alternatively, explore the more economical methods of lighting which have been developed in recent years.

Far too many foundries allow the use of open braziers intended for general heating purposes, but mainly used for boiling water for making tea. It is much more economical to instal proper heating methods or slow combustion stoves and provide a gas boiler for hot water supplies if no canteen facilities are available. Particular attention should be given to remedying all leaks in the compressed air supply. Quite a small escape of air runs away with a large amount of fuel and power.

Finally, institute and maintain a comparative record of the amounts of the various forms of fuel and power consumed so that wastage may be checked and the necessary economies definitely effected. If the size of plant permits, or if technical control is available, put a man in charge of fuel conservation, give him a copy of this article, and tell him to get on with the job.

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[1] F. W. Rowe, "Modern Problems and Developments in Engineering Bronze Founding," Proc. Inst. Brit. Foundrymen, 1924-25, vol. xviii, p. 456.

[2] F. W. Rowe, "Some Developments in Engineering Bronze Founding," Proc. Inst. Brit. Foundrymen, 1927-28, vol. xxi, p. 292.

[3] C. L. Cassidy, "Crucible Furnaces," *Foundry Trade Journal*, May 26, 1932, p. 319.

[4] A. Logan, "Non-Ferrous Castings," *Foundry Trade Journal*, March 19, 1936, p. 231.

[5] W. H. Smith, "Foundry Drying and Modern Core Shop Layout," *Foundry Trade Journal*, December 8, 1938, p. 423.

[6] "Core Drying Ovens," *Foundry Trade Journal*, March 3, 1938 p. 201.

PRESENTATION OF PAPER

Mr. Hudson's Summary

MR. HUDSON, introducing the Paper to the London Branch, said that in fuel-saving schemes more often than not it was the little things that mattered; and he emphasised that fact by recounting an experience he had had when in America. At that time he was associated with a firm which made all kinds of shovels and scoops of very high quality. The American railways were paying a bonus to locomotive crews, based on the amount of coal that remained on the tenders after locomotives had completed their trips. It was discovered quite accidentally that the crews which earned the biggest bonuses were always those which were using the firing scoops made by the company with which he was then associated. The company had wanted to get back one of those scoops for record purposes, but it could not buy one of them for any amount of money, as the men would not part with them. The reason was that the scoops were made in very high quality alloy steel—this was about the first application of alloy steel in shovel blades—and none of them ever broke in service; they always wore down as the result of constant scraping over years of use to about half their original length. The result was that the firemen could never put in more coal than was essential.

It must not be thought, however, that the locomotives were run less efficiently by reason of this system of firing. At that time the passengers on the principal trains in America could claim a rebate of fares if the trains were late. Therefore, punctuality was important to the operators of the railways, and they were able to run the trains on time whilst reducing the amount of fuel required to the minimum. This experience provided an excellent object lesson, as it were, in connection with fuel conservation in foundries, namely that in many cases it is the little things that matter.

Where Comparisons Fail

The Paper, he continued, which outlined some ways in which fuel economy could be effected in foundry practice, was directed particularly to the smaller founders, and he believed that such concerns would welcome some technical direction and guidance in this matter of fuel saving. The larger foundries, of course, had technical staffs available to give this matter the necessary attention. Since the Paper was distributed, written comments on it had been received from all parts of the country, and it had been interesting to note the comments on the figures which the authors had put forward as representative of reasonable fuel consumption in non-ferrous melting furnaces. It had been suggested that the data given in the Paper were a little out of date, particularly that dealing with the operation of brass foundry melting furnaces. Mr. Hudson admitted that that was so; but he added that, unfortunately, they were the only data that had been published within the last few years, and were included to demonstrate the effect of furnace type on fuel efficiency rather than to give the amount of fuel required. In a letter from one of the largest works in the country he had been taken to task somewhat for having quoted rather uneconomical ratios. In that letter the firm concerned had stated that, for a coke consumption of some 8 cwts., they melted more than 2 tons of gunmetal castings in natural-draft coke-fired furnaces. That ratio, of just over 1:5, was phenomenally good. Another firm, quite as big and just as well controlled technically, had stated that they melted 1 ton of gunmetal in furnaces of similar type for twice the coke consumption. If one firm could melt 2 tons for a coke consumption of 8 cwts., how was it that the other firm could only melt 1 ton for the same coke consumption? Of course, there were reasons. The first firm had a exceptionally large chimney, probably 100 ft. high, and their furnaces, although referred to as being of natural draft, were really forced-draft, because the draft through that chimney was equal to that which could be obtained by fan. The second firm, with the greater fuel consumption, had a smaller chimney and melted their metal from smaller heats. Many things must be taken into account in assessing the amount of fuel required for foundry melting operations.

Loss in Multiple Weighings

Recently, continued Mr. Hudson, a metallurgist whose name was a household word in the industry had said that he could not see how he could save fuel, for everything that he used was weighed and everything possible was being done. Many people might be inclined to say the same thing. But, said Mr. Hudson, that was not quite right. A little thought and investigation would show that there were loopholes, and that, although one might think, for example, that weights on paper were accurate, they were not so in practice. There was such a thing as overweight, and he believed Mr. McRae Smith would bring that point home very forcibly when he discussed cupola practice in connection with the iron foundry.

Core Oven Economy

Coming to the use of coke for purposes other than melting, Mr. Hudson said that during the last few weeks a number of people had told him that they knew their core stoves were inefficient, but that they could not achieve greater efficiency except by building new stoves. He did not think, however, that that was always the case. With a little ingenuity, one could modify existing plant, and some indications were given in the Paper as to how such improvement could be effected.

The finest system of core drying that he had ever seen was in Birmingham. The equipment in question had been developed by the Serck Radiator Company, and was known as the Serculator system. He had not seen it used in many foundries in this country. It was operated by hot air, the air being heated usually by gas and the products of combustion recirculated. The fuel consumption figures for that unit were noteworthy. Quite recently a new firm had started operations in Birmingham, and was in a position to convert existing core stoves to a very good fuel consumption basis at a reasonable cost, using a system rather similar to that just mentioned.

Stoving Eliminated

Continuing, he said he had visited one branch of the English Electric Company some two months ago, and had been very much impressed by their brass foundry, where moulds were dried without the use of a core stove at all. The company had discontinued the use of core stoves in this plant and had developed an inflammable mould wash which was painted or sprayed on to a green sand mould and then ignited; sufficient heat being thereby generated to effect skin drying.*

Anticipating the comment that no mention was made in the Paper of the saving of metal which could be effected by modifying gating methods, thereby reducing fuel consumption, Mr. Hudson said that that a very dangerous subject, because in that direction one could quite easily go astray and possibly produce bad castings, and the amount of fuel wasted as a result of that would be greater than any saving which might be effected. He, however, commended to the attention of non-ferrous foundrymen the recent Paper, by Taylor and Rominski,† on the novel method of gating and risering, and dealing with feeding by atmospheric pressure.

Mr. McRae Smith's Summary

Mr. McRae Smith, in his introductory remarks, confined his attention to possible economies which could be effected in the melting of cast iron in the cupola furnace. He felt that very little economy could possibly be made in foundries using hearth type furnaces. Electric furnaces, rotary furnaces, and so forth, were used with such great efficiency, and to their full melting capacity, that he could not see how the industry could really economise in the use of fuel in the melting of metal in furnaces of these types. He emphasised, however, the importance of operating furnaces to capacity, for part charges were extremely uneconomical and wasteful of fuel.

As to the possible fuel economies which could be effected in foundries using cupolas, he emphasised that in the Paper he had dealt with the problem entirely from the point of view of using existing plant. It was not his intention to discuss the ideal cupola or ideal cupola practice, but rather to show that it might be possible to effect very considerable savings in coke by adhering to certain rules in the operation of existing cupolas. Founders could not instal new cupolas at a moment's notice, even if the materials were available.

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* Walker, K. E., "Foundry Trade Journal," January 14, 1943.

† Trans. A.F.A., Vol. 50, 1942, pp. 215–259; also "Foundry Trade Journal," October 15, 22, 29, 1942.

As to the optimum size of cupola, he said that obviously, in foundries melting cast iron in cupola furnaces, the fuel consumption would be lowest where the size of cupola was reasonably adjusted to the volume of production of the individual foundry. Owing to the exigencies of present-day production, it was possible that a foundry which possessed a couple of 5-ton or 10-ton per hr. cupolas, might wish to melt in smaller quantities. In such cases he suggested the installation of false linings in order to reduce the effective diameter of the cupolas, for by that means considerable savings could be effected in the bed charges, which represented a very fair proportion of the total coke used when running a relatively small amount of metal in a comparatively large furnace.

The 6-in. Coke Split Standard

Frankly, apart from the above, he could not see that the foundry trade could effect any very great savings in respect of the amount of coke used in the bed in cupola melting. The amount of coke used in the bed must be a function of volume and not of weight. In a great majority of the smaller foundries the furnacemen were inclined to skimp the amount of bed coke used. Some very real savings of melting coke could be made, however, and in the Paper he had shown the simplest way in which to check quickly whether or not coke was being wasted. The melting rate of a cupola, of course, was not entirely dependent on the amount of coke contained in each "split" or melting charge. It depended also on the air pressure, provided the volume remained constant. When metal tapping temperatures were not quite so high as were desired, he suggested that the founders concerned should check the melting rate. From time to time he had been told, in foundries throughout the country, that the metal was not as hot as was desirable, and almost invariably he had found that that was due to the use of excessive amounts of melting coke. If "Old Tom," who was running the cupola, had a bad melt on one day, his natural inclination was to get into good grace with the manager, and he would put on more coke next day. The result was usually disastrous, and the metal on the following day was worse than before.

It would be generally agreed that, with British practice, and using British coke, the depth of the coke split was very important. It should not be greater than 6 in. In a great many foundries in this country, perhaps the majority, the depth was considerably greater than 6 in. It was necessary to determine the exact weight of any particular coke which would give a 6-in. depth, and then to decide on the metal charge as a ratio of that, instead of the other way round, as was too often the case. The actual melting ratio should vary between 8 parts of metal to 1 of coke by weight, and up to 12:1 for most types of metal charged or even 14:1 for phosphoric common iron. The difference between, say, a 10:1 and a 12:1 ratio, in terms of fuel saving, would represent a great deal if it could be achieved throughout the foundry industry. It meant a saving of about 3½ cwts. of coke for every 10 tons of metal melted.

Output per Square Foot

Mr. McRae Smith added that he wished to stress particularly the importance of checking the melting rate of cupolas. A melting rate of something like 0.6 ton per hr. per sq. ft. of melting area was not bad, but a rate of 0.75 ton per sq. ft. per hr. was easily possible. Indeed, it was possible to achieve, and he believed that some of the American foundries had claimed to have achieved, a rate of about 1.1 tons per sq. ft. per hr. Quite recently, however, he had found, in quite good foundries, that the melting rate was as low as 0.25 or 0.3 ton per sq. ft. per hr. These examples might be exceptional, but when one came across them haphazard one was inclined to think that there might be a good many others like that just around the corner. At any rate, the checking of the melting rate was a very simple method of showing the possibilities of saving coke.

Commenting on the use of a "boshed" type cupola, having a smaller diameter in the melting zone, in order to save bed coke, Mr. McRae Smith agreed that it was certainly advantageous from the coke economy point of view, and that there was a considerable number of such furnaces working satisfactorily in ironfoundries. Unfortunately, however, if there were no surplus capacity in the cupola, one could not afford to have the melting zone smaller because then one could not melt the required tonnage per hr. Further, he uttered the warning, in respect of the use of "boshed" cupolas, that if one were melting mixtures which must be controlled within very close compositional limits, there was danger of irregularity, but if one were melting only a phosphoric iron and close compositional control did not matter, then the "boshed" cupola would save fuel so far as the bed was concerned.

Tuyere Distribution and Area

In one of the written criticisms of the Paper, he continued, a correspondent had raised the question of the single row *versus* the double row of tuyeres, and had rightly pointed out that a lower bed could be used if there were only a single row of tuyeres. Without wishing to discuss in detail the respective merits of the single and the double row of tuyeres, Mr. McRae Smith said there was certainly some advantage in the double row, in that it gave more control of the air supply over a depth in the melting zone. From the fuel conservation point of view he suggested that founders operating cupolas having two rows of tuyeres should consider closing up the top row and opening out the bottom row to give the required tuyere area.

The importance of the proper tuyere area has been stressed very much by those interested in the technique of grey-iron melting, and his view was that a tuyere area of from one-quarter or one-fifth to about one-eighth of the melting area was quite satisfactory. Really, the matter was not so basically important as it was formerly thought to be, because, after all, the bottle-neck or restricted area in the cupola was at the melting zone, and the amount of air which would pass through the melting zone was probably very much smaller than was represented by the actual tuyere area. However, that was by the way.

Waste Through Multiple Weighings

A good many years ago, when he was concerned with the statistical side of the production of a small foundry, melting only about 350 tons of cast iron per month, it was found at stock-taking that about 550 tons of metallurgical coke was lost per annum. He was not inclined to believe it, although the actual stock figures at the beginning and end of a period of a year had differed by that amount. Actually it was due to the charging of extra coke on each charge beyond the amount shown on the charge sheet. Where 110 lbs. of coke were required, it was necessary to book out 120 lbs., because the cupola man, when weighing the coke, would put on a little extra. That was a matter of importance in the present circumstances of fuel stringency. It might not appear to be very serious for a man to add a last half shovel-full of coke to each charge, for it represented only 3 to 5 lbs. per charge. However, if one multiplied that by the number of all the charges that were made throughout the country in the course of a year, it represented a very substantial tonnage. Part of the 550 tons was also accounted for by the non-recovery of raw coke used in moulding pit beds and in large cores.

DISCUSSION

The BRANCH-PRESIDENT (Mr. R. B. Templeton) mentioned that, in the production of certain castings, where the cores were rather massive, the core makers used raw coke as a sort of fill-up. He asked what other material could be used instead of coke, bearing in mind that it was eventually thrown out with the cores and became waste material.

CAPT. J. G. BENNETT (Director, British Coal Utilisation Research Association) expressed his sense of honour and pleasure to be asked to speak, and said he had learned a great deal more from the remarks of Mr. Hudson and Mr. McRae Smith than he had known about foundry fuel practice before the meeting. His title to address the meeting was that he represented the Fuel Economy Committee of the Ministry of Fuel and Power, which was setting in motion a fuel economy campaign. Therefore, he would refer to the way in which the Ministry looked at the problem.

The fighting of a war, he continued, was a problem of men and materials, and we must think of everything we did in terms of men and materials. In regard to fuel economy, it was clear that the man-hours with which we were mainly concerned were man-hours of which there was a very serious shortage, *i.e.*, miners' man-hours. It was a help to the war effort if we could, by a lesser expenditure of man-hours and materials elsewhere, reduce the number of man-hours required in the pits to keep us supplied with coal. That was the basic principle of any economy campaign, and it must be the basic principle of a fuel economy campaign. It meant that, on the one hand, we must look back to the pit in order to see what was the ultimate result of any fuel efficiency effort, and on the other we must look into the manufacturing industries to see what it cost to bring about a given saving. The authors of the Paper had discussed the question as to whether renewals or alterations of plant for reasons of fuel economy could be contemplated. They had referred, very rightly, to the balance that must be taken between the risk of increasing wasters in production and cheese-paring on the fuel side. It was quite clear that fuel economy just for its own sake, without reference to its effect on production, might be a mistake.

New Plant not Banned

Those remarks, continued Capt. Bennett, might appear to indicate a negative attitude. But his reason for opening the discussion on these lines was to show that the Ministry saw the problem as a whole, and recognised that in some industries, perhaps not in the foundry industry so much as in some others, it was indispensable to encourage a certain degree of modernisation of plant and to allow maintenance and renewal expenditure in order that the plant should continue to operate at the proper level of efficiency. That was the attitude of the Ministry. Therefore, in discussing the subject in the broadest way, as he hoped the meeting would do, they should not turn aside entirely from considerations which might involve certain minor, and in some cases major, modifications of plant where they were quite satisfied that his first criterion was fulfilled, *i.e.*, that the ultimate saving of fuel in terms of man-hours, and the savings in the pits and on the railways, very handsomely offset the manufacturing effort required in making the modifications. There was a general tendency for suppliers of equipment to find that the Government Departments concerned with licences and with metal allocations were turning their attention to that aspect. It would probably be found that among the suppliers of foundry equipment there was a tendency to encounter an increased demand, and an increased readiness on the part of the Government Departments to encourage that demand where considerations of economy and efficiency were involved—fuel economy being one of the most important so far as the Ministry of Fuel was concerned.

Another part of the question of balancing was that they must think back to the ultimate goal of coal conservation. Referring to Table I in the Paper, which compared the thermal efficiencies of various types of melting furnaces, he said the figures as given appeared very favourable to electric melting. But if one took into consideration the efficiency of the power station, and of the transmission and transformation of electric power, which gave a figure for electric power delivered to a foundry of probably 18 per cent., and multiplied that by some of the efficiency figures in the table, which varied from 40 to 85 per cent. for electric furnaces, one would appreciate that the coal conservation aspect was quite an open one. He was accepting for the moment those figures which he believed represented the practice of some 15 years ago. He thought some advances had been effected in crucible melting which perhaps brought the balance still further in favour of some of the other methods of supplying energy. So that, from the national point of view in wartime, where they were concerned with coal conservation, they must consider how much loss was involved and how much material, man-power, and so on, were expended in supplying the energy used for a given purpose. That was a matter which clearly affected the policy of the Ministry and the Board of Trade in matters of licencing.

Most industries, whose representatives had met his Committee, had claimed that they had already cut their fuel consumption to the minimum. But he was much more inclined to accept the view of Mr. Oliver Lyle that there was no single factory in the country that could not cut down its fuel consumption by 20 per cent. without loss of production.

Clearly, sources of loss could more easily be spotted in the foundry industry than in a manufacturing process in which, for example, steam was used in a very complicated way, through an elaborate transmission system. However, in his view the Paper by Mr. Hudson and Mr. McRae Smith was immensely valuable because it considered secondary factors. It was often in the secondary processes, where the consumption involved was small in relation to the whole, that savings could be effected so great as to halve or quarter the consumption of energy for a given purpose. In many of the subsidiary processes in foundries there were substantial savings to be made quite apart from the cupola.

An Important Potential Saving

It was interesting to consider Mr. McRae Smith's remarks in support of the contention that in the major process of cupola melting in the iron-castings industry there were possibilities of quite considerable reduction of fuel consumption if all foundries could be developed to the level of the best. Assuming that the cupola melting ratios in the various foundries ranged from 7:1 to 12:1, and that the average was, say, 10:1, assuming also that the efficiencies in all those foundries could be raised to the level of the best; Mr. McRae's figure of 3½ cwts. of coke saving on 10 tons of metal would mean a saving of 30,000 to 40,000 tons of coke a year. That would represent a most acceptable gift from the foundry industry, and would place that industry very high among the good friends of the Minister of Fuel and Power.

But not only in the basic processes could considerable fuel savings be effected; there were also opportunities in connection with the subsidiary processes and in the application of heat generally in the works. The effect of the regulations covering the heating and lighting of works, under the new Factories Act, if applied completely to foundries, he believed, would be to increase considerably the amount of heat that would have to be put into the moulding shops. If the letter of the law were adhered to, the necessary increase in heat input would be quite serious. On the other hand, there were always possibilities of effecting considerable fuel savings in the heating of space by giving careful attention to matters which could be dealt with administratively, such as the prevention of air currents, and so on.

National Regional Fuel Committees

He was extremely glad to learn that the move to ensure the best efficiency in fuel-consuming processes in the ferrous and non-ferrous foundries was being organised; presumably the founders would make a study of fuel consumption figures in order to find the average consumption and how wide was the spread above and below that average, as well as of all secondary processes in which heat and power were used, with a view to the elimination of waste. That was a very important and necessary task, added to all the other important and necessary tasks which must be performed in wartime. It was quite true that at the moment we were facing a period in which the total war effort on the production side in this country would be conditioned by fuel and power supply. It was not only a question of the amount of coal the miners could raise, but also of the amount of electricity which could be generated in existing power stations. The grid was approaching its peak of possible output. The gas industry was hard pressed for supplies of industrial gas in various parts of the country; and we were strictly limited in respect of the amount of oil fuel we could import. Therefore, production and fuel economy were very closely bound together. That was recognised throughout the Government Departments, which were making a big fuel economy drive. Although fuel consumption was small in the foundry industry as compared with some industries, and although fuel cost represented a relatively small proportion of the total cost of producing castings, ferrous and non-ferrous, he did appreciate that attention would be directed to the problem of fuel economy through the very strong fuel committees which the industry was setting up, and which were in contact with the regional organisations.

Lastly, the Minister of Fuel and Power had asked the Controllers, who were appointed under the terms of the White Paper, to set up Fuel Economy Committees in the regions. In the London Region, Sir John Dalton had set up a Committee. If the London and southern foundrymen were not already in touch with that Committee, he would be glad to put them into touch with Sir John Dalton, who no doubt would be pleased to welcome on his Committee a representative of the industry. That link between the Regional Committees and the Committees of each of the industries was being strengthened, and was working extremely satisfactorily throughout the country. There was much less overlap or duplication of effort than one would expect from the impromptu way in which the fuel economy campaign was instituted; and he was glad to say that the returns received at the Ministry gave a very clear indication that the campaign was having an effect. If it were pressed by all concerned to the limit of their power, there was no reason to doubt that we should, without restriction of production in any essential direction, win through the coming winter. Next summer there were other possibilities of coping with the problem; the purpose of the immediate effort was to get through the coming winter.

Capt. Bennett again expressed his gratitude for having been permitted to address the meeting.

Electric Furnaces

Mr. V. C. Faulkner (hon. secretary of the Branch, and Past-President of the Institute and of the Branch) said that "tret" was the correct word given in the dictionary as representing the amount of a substance which was put on to a scale to make the beam go down. It was well known that in, say, the automobile foundries, where quite small charges were used in the cupolas, the annual paper loss as the result of the tret was extraordinarily high, whereas in foundries where the charges were large the tret was correspondingly low. It seemed, therefore, that if, instead of a charge of 1 cwt., one could work with 5 cwts., there would be a corresponding saving in the course of a year.

Referring to electric furnaces, the use of which was expanding rapidly in the foundry industry, he recalled that on one occasion, when he was starting up an English furnace in Milan during the war of 1914-18, the owner of the works there had asked him to take over a Bassanese furnace and to make some charges in it. It was of a type which he had never seen before, quite different from any he had handled in other countries. He had followed the normal English practice and had made a cast with about 850 units per ton; the previous average was 1,050 units per ton. Thus, an enormous saving was effected as the result of a change in process, and his process was adopted at that foundry. The fuel consumption had been reduced by about 20 per cent.

Commenting on the remarks made concerning the operation of melting apparatus to capacity, he said the most extraordinary Paper ever published on the subject was one from an American Navy Yard, where there were some English furnaces, amongst others, and where they were overloading their furnaces to something of the order of 100 per cent. They must have obtained some very wonderful results from the point of view of fuel consumption; but the life of the furnace roofs was about half that of the normal furnace roof. However, they could well afford to pay for that from the reduced fuel bill.

Well before the war, Germany was attempting to ration their ironfoundries, based not only on the most efficient cupola practice reported to them, but also for pig-iron as related to a return showing a minimum percentage of runners and risers. Obviously the two requirements in combination could not be met.

A New Feeding Process

Mr. A. C. Rhodes discussed a new process* of producing castings without the use of risers, and exhibited two valve lid castings in monel metal, made by that process, the castings being exhibited in the machined condition.

Mr. McRae Smith asked if they had been pressure tested.

Mr. Rhodes replied that they had been, and that they were perfectly sound. Describing the process, he said that the purpose of headers, risers or feeders on a casting was to provide a reservoir of hot metal to feed and fill up the cavity due to contraction on solidification, and considerable heat was wasted in melting more metal than was needed to fill the mould, since the header had to be of such dimensions that liquid metal would continue to fall into the vortex of the header until the metal had finally solidified. That period of time varied with the size, mass and type of alloy poured and with the temperature of casting.

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* Protected by Provisional Patents, but every facility will be given to concerns desiring to make use of the process.

Were it not for the loss of heat in the riser, due to conduction through the sand walls and radiation to the atmosphere, the riser itself would need to be no larger than would provide the metal for feeding. Many methods had been devised to augment feeding, such as rod feeding and steam pressure feeding. Both those methods had the disadvantage that, whereas the pressure on the liquid metal might be increased, considerable further heat losses took place, due to conduction up the rod and raising steam from the loam. Methods to prevent heat loss, such as surface powders, did not present a complete solution, as the riser must be of such size as to prevent any powder inclusion being drawn down in the liquid vortex entering the casting.

The process of after-melting which he described was one which enabled a casting or ingot to be made with no more increase in height at the point of feeding than was necessary to supply liquid shrinkage allowance. That allowance was calculated before moulding the pattern or was allowed for when making the pattern to give the required sink which would be quite level and free from cavity.

After the metal was melted and poured, an electric current was applied to the molten metal in such a way that melting continued at the point of feeding to prevent congealing around the walls of sand adjoining the feeding vortex and to ensure that molten and superheated metal would reach the centre of the mass to be fed. When the mass had set, the after melting ceased, resulting in a reasonably flat metal surface requiring only a normal machining cut to finish. No scrap feeder head had been melted, with its consequent wastage of fuel, and in the case of high-nickel alloys no expense of deterioration due to gas pick-up in the metal that would have been used; neither were there any labour or power costs involved in cutting off heavy risers. The current might be applied by carbon arc, resistance or induction, depending upon the size and mass of casting and the justification for constructing any special equipment. In the case of the two examples he had shown, which were two valve lids cast in monel, carbon arc flame was applied to effect that melting. The total sink in the top surface was approximately $\frac{5}{16}$ to $\frac{1}{4}$ in., and a $\frac{3}{32}$ in. deep facing cut proved the tops to be clean and solid.

Recalling that Mr. Hudson had shown that valves of that type were obtained in high-nickel alloys consistently sound only if poured directly on top with strainer runner and direct feeder under it, Mr. Rhodes said that valves made in that way weighed 15 lbs., valve and header together, without strainer. The two comparable examples shown, however, weighed only 3 lbs. 10 oz. each as cast—a difference of more than 11 lbs. on each casting.

In reply to a question by Mr. Hudson, as to whether the cost of the current used would not outweigh the amount of heat used in melting the header, Mr. Rhodes said that only 0.9 to 1 unit was used from the commencement to the finish of the arcing period. It was found that intermittent periods of arcing only were necessary, so that more than one riser could be dealt with by one arc. Obviously, a greater heat equivalent than one unit would be required to melt the metal for the header.

The **Branch-President** said it was interesting to reflect that, for every 100 tons of metal melted, about 60 tons of castings were produced.

Mr. McRae Smith said that in most iron foundries the weight of castings produced was about 60 to 65 per cent. of the weight of metal melted.

The **Branch-President** added that the liquid shrinkage varied, with the composition of the metal, as from 1 to 5.

Eliminating Venting Coke

Mr. L. E. Slater, commenting on the Branch-President's reference to the use of material other than coke in large cores, pointed out that the slag running from the furnaces was always a bugbear. If it were run into a tank of water, it would granulate, and he suggested that in that condition it might be used quite safely inside the cores. At any rate, he had found it to be quite useful for that purpose, though perhaps the moulder might object to it because it was something new. The slag granulated into quite small pieces, and was quite light.

In reply to the Branch-President, he said that a tank was provided under the slag hole. But he warned against the use of a bucket, for that would soon be holed.

The **Branch-President** remarked that the suggestion was quite a good one.

Fuel Savings in Brass Foundries

Mr. C. F. Atchison, discussing fuel consumption in a well-run brass foundry, melting presumably with crucibles, said that a consumption of 1 ton of fuel per 5 tons of bronze or brass could be achieved in any reasonable crucible furnace; and it could be beaten in many cases. On the other hand, one sometimes came across brass foundries in which two or three times as much fuel was used, particularly jobbing foundries which were doing heavy work. He appreciated, however, that it must be very difficult to achieve a low fuel consumption figure in such foundries. In some cases they would put the pot on during the morning, although the metal was not required until the afternoon, and that was the cause of the waste as a rule. The remedy was to organise practice so that the metal was ready only just before it was required, and not a long time before.

Speaking on behalf of his colleague, Mr. W. C. Cathcart, who had made some notes on non-ferrous melting, he referred to crucibles, urging that founders should use pots which would conduct heat better than would the old-fashioned pots, and that they should keep the pots clean. Sometimes one saw pots so drossed up that the time required for melting the charges was 25 per cent. longer than the normal; that was bad for the pots, and also from the point of view of fuel conservation.

Another matter mentioned by Mr. Cathcart was that of blowing coke holes. Sometimes there was so much blowing that half the heat of the fuel came out in the form of carbon monoxide, at the waste gas outlet, and before the melt was completed there was hardly any coke left in the furnace. That was a constant problem, necessitating careful and intelligent control of the blast damper.

Again, quite frequently one found more furnaces at work in a foundry than were really needed for the work in hand. The foundrymen, of course, were ensuring that they should have available the metal they required or might need at the time they used it. In these days at any rate no furnace should be lighted that was not really needed for the amount of work to be done, and he would be interested to know how that problem could be solved.

The **Branch-President** could only suggest that more propaganda by the Ministry of Fuel and Power might help.

Mr. Atchison promised to send a copy of Mr. Cathcart's written comments to Capt. Bennett, who assured him that they would be most acceptable.

Economising in Oil Fuel

MR. A. HAYES was rather peeved that no reference had been made to the use of oil fuel, for the foundry with which he was concerned was operated almost entirely by fuel oil-fired furnaces. A visitor to that foundry, he said, might be excused for thinking that it was practically impossible to waste fuel when using those furnaces; but, unfortunately, there was a considerable waste in oil fuel. During the last few weeks he had made a number of investigations at his works in that connection. In the first place, he had found that there was new labour coming into the works which was totally unaccustomed to the type of work done. These people thought, for example, that by turning up the oil supply on a furnace they achieved faster melting; unfortunately, however, it was found that that resulted in getting carbon into the combustion chamber, which ultimately slowed down the melting. Then he had run a series of tests involving the provision of a calibrated supply tank for each furnace; and by examining the linings and crucibles when they were broken he had found that the furnacemen whose habit it was to run their furnaces hard, *i.e.*, to use excess oil, were also very heavy on the wear and tear of the bricks and crucibles. To overcome that difficulty he was fitting a flow meter to each furnace, which would show the exact consumption of fuel oil, so that he could prove to any furnaceman whether or not he was exceeding the standard allowance. It was the policy of the management to have one of the laboratory staff available to stand with the furnaceman and operate the furnace with him if the operation were unsatisfactory. That had more or less a psychological effect; the furnaceman knew that somebody was taking an interest in him, and Mr. Hayes believed that a considerable amount of fuel oil was saved as a result—or at least that would be so as soon as the scheme came into full operation.

Further, he was running a technical class for furnacemen once a week, at which he lectured on the technicalities of the job in very simple language. It was his experience that, when there were newcomers into the industry, who knew nothing about it, they would ultimately respond if the management took sufficient interest to lecture and to try to help them with their job. He did not claim there would be immediate response, but there would be response ultimately.

CAPT. BENNETT asked if Mr. Hayes was able to secure deliveries of flow meters.

MR. HAYES replied that he was trying to secure delivery at the moment.

CAPT. BENNETT said that he and his colleagues at the Ministry were very much concerned with the poor delivery of instruments, resulting from the big demands that were being made on the instrument makers. They were hoping to make arrangements to secure centralised purchasing for certain types of meters, through the Ministry, to enable supplies to go through in bulk and so be expedited. If those who experienced difficulty in connection with deliveries of measuring instruments which were essential for fuel economy would write, through their appropriate Fuel Economy Committee, or direct, to the Secretary of the Fuel Efficiency Committee at the Ministry at Dean Stanley Street, Westminster, S.W.1, the Ministry would do all it could to help things forward.

MR. HAYES added that a further consideration arising from fuel economy was that of profits; every gallon of fuel oil saved meant a saving of 9¼d.

Compressed Air Wastage

MR. E. H. BROWN emphasised that one of the most serious wastages in the average foundry in this country was that of compressed air, and said he did not think that half the foundrymen appreciated how much compressed air cost. In perhaps 30 per cent. of the foundries in this country to-day, when moulds had to be blown out, the men would use the nearest air pipe and turn on the blast, without any attempt to cut down the jet. One particular firm, which had introduced proper valves for that purpose, had reduced its compressed air bill by 45 per cent. In the average shop nearly one-third of the air was wasted.

The BRANCH-PRESIDENT agreed.

MR. BROWN added that the cost of compressing air, in terms of electric power alone, was not light; if something could be done generally to reduce that wastage throughout the whole industry it would mean a very considerable fuel saving in the aggregate.

Another source of waste was the open brazier. He appreciated that it was not possible to eliminate its use in every shop. Too often, however, when an open brazier was required, the men would knock a few holes in a 5-gallon drum, make a coke fire in it, and place it over the job they were doing. It would be well in some cases to cut it in half vertically when using it for drying moulds; that would reduce the effective heating area at the bottom, without reducing the depth of the fire, and the amount of coke used would be reduced considerably.

A Timely Reminder

MR. G. C. PIERCE (Past Branch-President) said he had listened to the discussion with mixed emotions, and he felt it was time that somebody took up the cudgels for the Institute of British Foundrymen. "The Foundry Trade Journal" and the foundrymen themselves at the meetings of the Institute, had been discussing and urging fuel economy for years, and many new methods had been adopted from time to time to secure it. He was one of the foundry managers who were continually trying methods which would save coke, oil, etc.

Commenting on the reference in the Paper to an overall metal to coke ratio of 2:1 in the case of gunmetal, *i.e.*, 2 tons of gunmetal per ton of coke, and to the fact that experience showed a considerable variation in that ratio as between different foundries, he pointed out that a very large variation was to be expected between two foundries if one were producing billets only and the other producing a similar tonnage of castings. Bearing in mind the allowances for runners and risers, one would not expect the foundry which was producing castings to compete with the ratio achieved in the foundry producing billets.

It would be appreciated, of course, that the authors of the Paper, both of whom were very prominent foundrymen and metallurgists, did come into contact with some extremely bad cases, because they were called in to advise in those cases. In the main, however, whilst no one would disagree that it was incumbent upon all foundrymen to economise in fuel as much as possible, he ventured to say that every responsible foundryman had had in his mind for a considerable time the importance of fuel economy, and had done something in that direction. Bearing in mind that they had been studying the problem for years and were flattering themselves that they had effected economies, they did not like to be told that they were naughty boys. Indeed, he said jocularly, "I won't have it." He felt bound to say something in defence of the poor foundry people who were actually doing the job.

The BRANCH-PRESIDENT quite agreed, but added that the object of the Paper was to help the halt and the lame, and not to criticise those who were nearer perfection.

Standardising Unit Conversion

MR. P. T. HOLLIGAN, recalling Mr. Hudson's reference to a new system of core drying which was available, asked for the name and address of those who were concerned with it, so that he could learn more about it. Foundrymen, he continued, were being asked, quite rightly, to make returns of their fuel consumption per lb. or per ton of finished castings. As he viewed the situation, however, surely they should return, not only their direct fuel costs, such as the costs of the oil or coke or other fuel or power used for melting the metal and making the castings, but also their indirect fuel costs, including the cost of power for driving conveyors, of electricity for lighting, and so on, all of which had to be considered in arriving at the fuel cost of the finished castings. It might be helpful to the foundry industry if the Ministry of Fuel and Power could indicate some means of conversion to common units. For instance, the management had to consider electricity in terms of kVA., fuel oil in gallons, coke in lbs., gas in therms, and so on, and it was necessary to bring them down to a common basis when discussing consumption. One foundry would give figures in terms of gallons of fuel oil per lb. of metal, another would give returns in terms of electrical units, and another would quote therms of gas. Some poor people would suffer headaches when attempting to convert those figures to a basis on which comparisons could be made, and to put forward a fuel target.

After inviting Capt. Bennett's comments on the use of creosote pitch as an alternative to fuel oil, he asked if Mr. Hudson had any suggestions to make concerning the optimum time for loading crucibles, it being borne in mind that the furnace operator had to heat the furnace, pre-heat the crucibles, and at the same time control metal quality and fuel consumption.

Creosote Pitch as a Fuel

CAPT. BENNETT, replying to Mr. Holligan's question, concerning the use of creosote pitch as a fuel, said that many difficulties were encountered when its use was first attempted, but he believed that they had since been straightened out, and it was working quite well in those applications for which it was suitable. There was, however, a demand for creosote for other purposes, and the ability to use pitch without creosote "sweetening" would be very attractive to the Ministry; the matter was still being pressed. The purely technical considerations, which concerned the application to one kind of melting process, might with advantage be discussed in the Institute by members who had had experience of its use, or through the medium of "The Foundry Trade Journal." There should be exchange of information between those who had used the fuels which the Ministry would like to see in use in wartime.

With regard to a common basis of assessment of fuel consumptions, he was immensely relieved to be asked only to give a set of conversion factors as between different types of fuel. He was afraid the meeting would have asked—and it would have been legitimate—how to assess the fuel consumption per unit of finished product when the finished product itself could vary from billets to castings involving a great deal of machining, as well as varying losses from risers. It was clear that that could be settled only by a committee of experts. The foundrymen themselves must agree on a factor which would bring them to a standard product; that was a most valuable function of an industry's Fuel Efficiency Committee, the work of which would be of permanent benefit to the industry as well as of great assistance to the Government. Nobody else could do that as well as could the members of the industry concerned. However, the Ministry had a table of conversion factors covering the different kinds of fuel, and he would see that copies were made available to the Institute and the industry.

The New Feeding Process

MR. HUDSON, dealing with Mr. Rhodes' reference to the feeding of castings by a method which involved the use of an electric current, said that the process described had been used widely in America; it was used, for example, by his own company for the feeding of large ingots in nickel, monel, and so on, and there was no doubt that it was a very useful method of eliminating the excess metal normally used for the provision of feeding heads. He was very interested indeed to learn that Mr. Rhodes had used it, for he did not think it had been applied extensively in connection with sand castings. The type of casting exhibited by Mr. Rhodes was such that the method could be applied to it readily; but for the majority of castings it might not be applied so easily.

Mr. Hudson then dealt with Mr. Atchison's question concerning the training of foundry operatives, and said that if the various trade associations throughout the country can get going on the Ministry of Fuel scheme for forming the industry's Fuel Committees, advice and help would be made available in the regions by the industry itself, and it could be passed on to the founders who really needed some help.

Expressing some sympathy with the remarks of Mr. Pierce, he said he appreciated that many foundries were doing their best to ensure fuel economy. Not only the big firms, but some of the small firms also had done very well in that direction. The idea of the Paper was to speed up the laggards.

Core Venting Coke

MR. MCRAE SMITH, dealing with the use of coke for venting and filling in large cores, and moulding pit beds, etc., said it was mentioned in the Paper because it was one direction in which coke was certainly wasted, and it was necessary to face that fact. As he had mentioned in the Paper, the use of porous material such as blown crushed slag might be considered. It might be prepared on the premises from cupola slag, by air blowing or other methods. No doubt the ingenuity of the foundry industry would find the answer to the problem eventually. One suggestion was that there should not be any filling at all, but that the core should be in the form of a shell, with vent pipes carried across the gap by various means, instead of using an ash- or coke-filled cavity to conduct the gases away. On medium size cores some foundries used perforated loam bricks of irregular shape in place of coke or ashes. It had been suggested that the coke which was used for that purpose all came back from the fettling department and was used again, but that was not the case. One foundry manager had recently stated he had been looking into the matter and had estimated that about 50 tons of coke was lost in his foundry each year through that source—and it was only a small foundry.

Commenting on Mr. Brown's reference to the wastage of compressed air, he said he felt very strongly about it, and it would not be safe for him to say all that he thought about it. In the penultimate paragraph of the Paper it was urged that particular attention should be given to remedying all leaks in the compressed air supply. Probably more air was lost in that way, and consequently more fuel was wasted in producing power for compressing the air, than was used legitimately from the compressed air lines, with properly constructed nozzles, for blowing out moulds. In wartime it might be advantageous to revert to the old-fashioned bellows.

Expressing disagreement with Mr. Brown's view that the open brazier could not be dispensed with entirely, he said it was purely a matter of supervision, organisation and management, and he did not see why it was necessary to use open braziers in any foundry. Portable heaters, fan-driven or compressed-air-driven, could be used for drying moulds, or the jobs could be dried in the stove, or a torch could be used for skin drying. Of course, braziers were used very wastefully for making tea, and so on. Perhaps the only legitimate use of braziers was for thawing frozen sand in emergencies during the winter, particularly in the northern districts, and where sand drying plant was not available.

It was pleasing to hear the remarks of Mr. Pierce concerning the achievements of the foundry industry in the direction of fuel economy. Neither Mr. Hudson nor himself was in any way disparaging the work already done by the Institute in that direction. The people they wanted to get at were those who did not read the information given on the subject in "The Foundry Trade Journal" or the Proceedings and Reports published by the Institute. In regard to cupola coke beds, he did not think that any further great saving could be made. In some cases they might even reduce wasters, and consequently save man-hours, by increasing coke consumption there, but he did criticise the use of excessive fuel in the "splits" for melting the charges. Many foundries, perhaps 50 per cent. of them, if they would study very thoroughly the melting rate problem, would find that they could make really worth-while economies. In so doing they would improve the quality of their metal by achieving higher temperatures and quicker melting, and thereby reduce the number of waster castings produced.

The BRANCH-PRESIDENT, at the conclusion of the discussion, emphasised the necessity to do everything possible to save fuel. It might be difficult, he said, to work up all the enthusiasm necessary among some of the workpeople, but he suggested that the Ministry of Fuel and Power might with advantage issue posters carrying slogans, as other Ministries had done. Posters of the "Dig for Victory" type might do a lot in the desired direction.

Vote of Thanks

DR. A. B. EVEREST (Past-President of the Branch), proposing a vote of thanks to the authors for their Paper, and to Capt. Bennett for having added so much to the interest and value of the discussion, said he had waited for the authors to emphasise the dangers of over-economy, for then the fun might have begun. Economy might be practised to such an extent as to give rise to the production of wasters, so that extra melting and extra man-hours were involved. But that was a very controversial subject, and he admired the way in which the authors had kept clear of it.

MR. P. D. PINCOTT, seconding, said he was somewhat in sympathy with the remarks of Mr. Pierce, particularly knowing the difficulty of ensuring that the foundrymen would use the weighing machines and measures provided for them. However, he endorsed wholeheartedly the recommendations in the Paper, and urged foundrymen to endeavour to fulfil them.

The vote of thanks was accorded with acclamation; and thanks were expressed also to Mr. Faulkner for having organised the discussion.

WRITTEN DISCUSSION

EFFICIENT NATURAL DRAFT FURNACES

MR. W. MACHIN wrote: I have been interested in the reading of the Paper which has been circulated in connection with conservation of fuel in brass and iron foundries, especially so in the reference the authors make to C. I. Cassidy and A. Logan and their remarks regarding natural-draft pit fires and their efficiency. In this reference mention is made as follows:—"Taking an overall efficiency of 1.2, the fuel required to melt a ton of gunmetal would be half a ton." It is then stated that every possible use should be made of forced draft instead of natural draft.

I would like to point out that the results given in this Paper concerning natural-draft pit fires are not in accordance with the results which are being obtained at Barrow-in-Furness, where we find the natural-draft pit fire furnaces better, both for speed in melting and quality of metal, than is the case with the forced-draft furnaces of the same type. In view of this, the reference put forward by the authors would appear to be incorrect.

The result taken from actual practice in the brass-foundry where there are a large number of natural-draft pit fires which will melt 400 lbs. of gunmetal, each separate melt, is as follows:—Coke consumption, 8 cwts. 2 qrs. 18 lbs.; gunmetal melted ready to cast, 2 tons 2 cwts. 3 qrs. 12 lbs.; and similar results to this are being obtained daily.

I would like to ask the authors what their experience is with the life of crucibles, which is a very important item these days when using same in forced-draft pit fires as against a pit fire worked under natural-draft conditions, also whether they would advise the change-over of the fuel consumption as given under our method.

In connection with the authors' remarks concerning natural-draft coke-fired furnaces, I agree that it is necessary to clean out flues, and twice a year is suggested. Unless this is done, one would eventually come to a standstill, but, as regards the installation of a draft gauge on the stack, I would like the authors' opinion as to the amount of draft they consider necessary at the base of the stack to get the best results in speed of melting and consumption of fuel.

Authors' Reply

The authors fully appreciate the fact that some of the data given at the beginning of the Paper regarding the fuel consumption of various types of brassfoundry melting furnaces may now be out of date. These data were recorded primarily to supply some evidence that air supply was an important factor in coke-fired crucible furnaces and were not intended to be accepted as a guide to fuel consumption. The coke-to-metal ratio of approximately 1:5 quoted by Mr. Machin is extremely good for natural-draft crucible furnaces, and one can only imagine that a stack of considerable size is being employed, creating a powerful draft. The use of 400-lb. crucibles in pit fires is also unusual for most foundries, and there is no doubt that this will also have a material effect in obtaining a low fuel consumption.

Some modern figures obtained from one or two of the larger non-ferrous foundries with reference to the fuel consumption of various types of furnaces are tabulated here (Table A).

So far as the efficiency of coke-fired furnaces is concerned, there are so many variables in practice that it is extremely difficult to draw conclusions, apart from there being some indication that, when plenty of air is available, the coke consumed is less. Furthermore, the true efficiency of coke-fired furnaces over a long period is much less than that shown by individual or a short series of melts. Under such circumstances too much emphasis should not be laid on furnace efficiency, but on the amount of fuel required in the foundry to produce a unit weight of finished castings.

In regard to the comparative life of crucibles fired by natural and forced draft, it is rather difficult to give a definite answer on this point. So many natural-draft furnaces work with hardly any draft at all, whilst, on the other hand, some of the rapid melting forced-draft furnaces on the market to-day are being blown to death. Over these two extremes some difference in crucible life may be detected in favour of the natural-draft furnace. When one compares, however, a natural-draft furnace with adequate air supply, and a properly blown forced-draft furnace, crucible life should be approximately the same.

Regarding the amount of draft required, this will vary according to the size and number of furnaces and the type of alloy being melted. It is, therefore, rather difficult to make a definite statement on this matter without knowing all the facts of the case. The performance of Mr. Machin's furnaces is, however, very similar to that obtained from a 400-lb. coke-fired Morgan tilter and the volume of air required for melting gunmetal given by the makers of that furnace is summarised below:—

Air requirements.	Size of furnace.	
	200 to 250 lbs.	400 to 450 lbs.
Pressure (inches of water) ..	3	3½
Volume (cu. ft. per min.) ..	300	350

It should be noted that these data apply to fan requirements, and it is usual to allow for approximately double the quantity of air required to burn the coke (1 lb. of hard coke requires about 165 cub. ft. of air) to take care of leaks, etc. Accordingly, for the air measurement at the base of stacks about half the figures given above for volume might be taken as a guide. The air pressure should be not less than 2 in. Air requirements can always be readily checked by calculation on any particular installation when full details are known. In view of Mr. Machin's excellent results, however, the best advice that can be given is, leave well alone.

CRUCIBLE FURNACE PRACTICE

Mr. W. C. Cathcart wrote:—

This Paper particularly so far it deals with non-ferrous foundry melting practice has been read with interest. Though prefaced by tables somewhat antiquated, drafted to show differences in thermal efficiency and cost of working of various types of melting unit, the authors have evidently confined themselves mainly to the important task of advising melters on the steps that can at once be taken to reduce fuel consumption with existing melting equipment. Nevertheless, the opportunity might perhaps be taken to criticise certain figures in Table I, in which furnace thermal efficiencies are compared.

To bring the figures to bear correctly on the point at issue—fuel consumption—those quoted for the electric furnaces must surely be multiplied by the thermal efficiency of the power station, approximately 20 to 25 per cent. for a modern plant. It might also be noted, that while melting in direct contact with flame in a reverberatory furnace can generally be carried out with less fuel than in a crucible furnace, the factors of loss of metal by oxidation and of quality of castings must always be taken into account, particularly to-day, when such volatile metals are in short supply, and the saving of shipping space is so essential. It is considerations such as these that generally and rightly govern the type of furnace installed.

The vast majority of non-ferrous metal founders depend on crucible furnaces for melting their metal. The pamphlet under notice contains a great deal of advice that should prove of much service in reducing fuel consumption. There are, nevertheless, one or two points that have been omitted, no doubt for reasons of brevity, and in view of the importance of the problem, I make no apology for bringing them to the notice of members:—

Fuel can obviously be saved by: (1) The selection of a more suitable type or quality of fuel; (2) ensuring perfect combustion of the fuel; (3) using a crucible of better thermal conductivity; (4) reducing heat losses; (5) better maintenance of furnace equipment; and (6) improved planning and control of furnace operation and output.

Quality of Fuel and Combustion

Quality of Fuel.—This has been well covered in the Paper. It is obviously bad practice to use gas or other soft coke for higher temperature melting and for forced-draft furnaces when supplies of hard fur-

Table A.—*Fuel Consumed on Various Types of Furnaces Melting Gunmetal and Bronze.*

Firm.	Type of Furnace.	Fuel to metal ratio.	Remarks.
	Coke fired—		
A	Natural-draught lift-out crucible	1 : 5	400-lb. crucibles and high stack.
B	,, ,, ,, ,, ,,	1 : 3.5	300 ,, ,, melting ingots.
	,, ,, ,, ,, ,,	1 : 2.5	300 ,, ,, ,, virgin metals.
	,, ,, ,, ,, ,,	1 : 2.75	100 ,, ,, operated at full capacity.
	,, ,, ,, ,, ,,	1 : 2.25	100 ,, ,, ,, half full.
E	,, ,, ,, ,, ,,	1 : 3.6	300 ,, ,,
B	Forced-draught tilting (low pressure)	1 : 3.5	400 ,, ,,
C	,, ,, ,, ,, ,,	1 : 5.4	600 ,, ,,
D	,, ,, ,, ,, ,,	1 : 4.2	400 ,, ,,
E	,, ,, ,, ,, ,,	1 : 4.2	400 ,, ,,
C	,, ,, lift-out crucible (low pressure)	1 : 3.8	250 ,, crucible
	,, ,, ,, ,, ,, ,, ,,	1 : 3.6	150 ,, ,,
D	,, ,, ,, ,, ,, ,, ,,	1 : 2.3	150 ,, ,,
F	,, ,, ,, ,, ,, (high pressure)	1 : 4.4	Square lining.
		1 : 6.3	Above altered to radial lining.
	Oil fired—		
D	Lift-out crucible	1 : 7.0	150-lb. crucible.
	Tilting crucible	1 : 8.0	400 ,, ,,
G	Non-crucible Sklenar type	1 : 13.3	300 ,, furnace.
H	,, ,, ,, ,,	1 : 11.0	½-ton furnace.
	,, ,, ,, ,,	1 : 13.8	1 ,, ,,

nace coke are obtainable. The hardest types of Durham beehive coke will prove the most economical for use in tilting furnaces and for melting high-nickel alloys in pit fires. Much waste will be experienced with oil furnaces if efforts are made to fire them with high-viscosity fuel without providing means for warming the oil to a satisfactory degree of fluidity, and without adequate filtering.

Combustion.—The Paper rightly lays much stress on the need to ensure perfect combustion. No doubt we should see more draft gauges registering forced-draft blast pipe pressures if they were not so liable to breakage by rough treatment. A large amount of coke can be saved if melters make a practice of reducing the blast or draft as the coke burns away towards the end of the heat. Coke furnaces, which in practice must be intermittently fed with fuel, are normally overcharged with coke at the beginning, and undercharged at the end of heats. The best compromise consists in blowing up a good melting heat to begin with, holding that temperature as the heat proceeds, and the coke burns away with a progressively reduced blast or draft. In the case of a blown furnace. when there is generally some pressure in the top of the combustion chamber, an indication can be given to the fireman by providing a small hole in the cover, through which a flame of combustion products will appear, the colour, volume and shape of which will tell the melter when he should adjust the blast, or, if necessary, poke the fire and recoke it.

Air control dampers must be kept in good working order, and be capable of being clamped in any position. In the case of oil and gas furnaces, the authors of the Paper describe clearly similar means normally available, to check the oil or gas and air ratio, and the fireman must be trained to adjust the oil or gas supply as soon as the flame indication departs from the normal.

Crucible Conductivity and Heat Losses

Conductivity of Crucible.—The Paper omits to recommend the use whenever possible of the modern rapid heating crucible, by means of which melting can be carried out in 20 to 25 per cent. less time, and with a corresponding reduction in fuel. Most crucible makers automatically supply this type of pot for use in tilting furnaces, but generally only do so on demand in the case of pull-out pots. When they are adopted, it is invariably found that the desired output can be obtained with fewer furnaces in commission. It is essential that pots should be well scraped out inside, as soon as the metal has been poured. A layer of dross allowed to freeze and build up slows down the melting. Adhesions of slag on the outside must also be removed for the same reason.

The conducting element of the pot is graphite, which will slowly burn away if exposed to oxygen at red heat. Crucibles are manufactured with a protective glazed surface, designed to minimise this burning or perishing. At maximum temperature of use the crucibles become more or less self-glazing, but at lower temperatures any damage to the glaze will permit perishing to occur, and the thermal conductivity of the pot will be lowered. For the protection of the pot from internal perishing the presence of the metal is mainly relied on. It will therefore be realised that, apart from the obvious waste of fuel, it is bad practice to hold a red hot crucible empty for long periods, as there will be serious burning or perishing of graphite and a permanent reduction in conductivity.

Heat Losses.—Wherever possible a course or backing of insulating bricks or material should be provided behind the refractory lining of the furnace. Waste gas outlet ports or flues should be maintained at the size recommended by the furnace builders and must be patched or rebuilt as soon as they wear oversize. In furnaces where the charge in the crucible can radiate heat to the foundry, the pots should be covered.

Furnace Maintenance and Operation

Maintenance of Furnace Equipment.—It is a matter of concern to observe how many furnaces are operating to-day with defective air dampers or with dirty oil burners. In many oil furnaces their efficiency is badly affected by incorrect positioning of the burner relative to the blast inlet. It is essential that the adjusting devices provided with the plant are kept in first-class workable order, and for this purpose periodical cleaning at week-ends is essential. The Paper emphasises the need to maintain furnace linings at their correct dimensions. Especial care must be taken to avoid straining the pots, the premature failure of which leads to serious damage to the furnace refractories by the action of spilt metal.

Control of Furnace Operation and Output.—The Paper warns melters against the loss of heat that will be experienced if crucibles are not charged with metal to their capacity. Lightweight heats are most wasteful. It should also be remembered that a heat from cold takes at least 50 per cent. more fuel than a " hot start " heat. The practice therefore of lighting and using more furnaces than necessary and working them below their capacity is very wasteful. The lighting of a furnace should be timed so as to produce its molten metal at or near the time at which it will be required by the moulders and not, as so often occurs, well before that time. With pit fire practice the pot should be poured as soon as it is ready and should be immediately replaced in the hot furnace and recharged. The practice of using two sets of pots alternately, allowing them to go cold between heats is bad and wasteful from every point of view.

Conclusion.—If foundry managers, bearing in mind the scarcity, to say nothing of the value of the fuel that is expended in their foundries, will arrange that these costly heating processes are properly supervised and the personnel adequately instructed, they should have no difficulty in handsomely beating the figures of fuel consumption quoted in this pamphlet, with benefit to themselves and the national effort.

Authors' Reply

The authors are much obliged to Mr. Cathcart for his carefully considered and constructive remarks and his views are, furthermore, warmly welcomed as they represent the views of the furnace-maker, as distinct from the user.

It is agreed that the data shown in Tables I and II are to-day somewhat out of date. Unfortunately, they appear to be the only published figures available and were included in the Paper not so much as to indicate matters of fuel efficiency, but rather to emphasise that forced-draft crucible furnaces seem to be more economical on fuel than natural draft.

The authors are indebted to Mr. Cathcart for drawing attention to several additional matters, which might be considered in connection with fuel conservation and they wholeheartedly endorse his remarks, but would like to point out that in connection with point 1—the selection of a more suitable type or quality of fuel—there are two sides to this question. In wartime, supplies of the most suitable type of fuel may not always be available and, therefore, it is considered that a more useful line of thought lies in guiding the non-ferrous foundryman as to how he can best use available materials. An attempt has been made in the Paper to do this.

Mr. Cathcart's concluding remarks should be particularly emphasised. There is plenty of scope in the majority of non-ferrous foundries throughout the country for improving the upkeep and maintenance of melting equipment and attention to this point, in conjunction with the adequate instruction of furnace operators, will undoubtedly play an important part in the economical use of fuel.

RELATIVE EFFICIENCIES

MR. J. ARNOTT wrote:—The various ratios given represent a lower efficiency than the probable average; he could produce figures which his firm had taken at various times. The tests were very carefully observed, and the material was all used for making of castings, *i.e.*, it was up to the full pouring temperature, and the material in all cases was pre-war A.G.M. The care given to the test refers to the recording but it does not imply that there was any abnormal attempt at economy. The tests on the contrary were really an observation of existing practice and were not designed to prove anything or even to make comparisons.

(*a*) *Pit-type Natural-draft Crucibles* (300 lbs.).—Average coke consumption, 82 lbs., giving ratio of 1 coke to 3.6 metal.

(*b*) *Coke-fired Tilters* (400 lbs.).—Six heats per 8-hr. day. Two different makes of these furnaces are installed. In one the ratio was 1 coke to 4.15 metal. In the other 1 coke to 4.4 metal. A more recent test carried out in the presence of a representative of Glasgow Corporation Gas Department gave a ratio of 1 lb. coke to 5.4 lbs. metal. In this case 7 heats of 400 lbs. were run in an 8-hr. day. He would not give this as a representative average, and thought a figure of between 4 and 4.5 lbs. metal per 1 lb. coke is more dependable.

(*c*) *Air Furnace.*—On an observed melt of 7 tons 13 cwts. the ratio was 1 of coal to 3.15 of metal.

No figures are available of oil melting because the foundry does not use oil for melting gunmetal.

Table II is of very little service since it does not give the ratio of metal melted to fuel used, and it does not even mention the type of fuel. He suggested that some directions in which overall fuel economy might be effected are as follow:—

(1) To check the ratio of the total metal melted to the finished castings despatched from the shop and make an attempt to cut down this ratio. Improvement can be effected by eliminating excess metal through greater precision in estimating the weight of castings. Moulders generally err on the safe side, and it has been found that nearly always some metal remains to be ingoted after the jobs are cast.

(2) The ingoting of borings can be reduced or eliminated by using a greater percentage in the charges to be poured directly into castings. The latitude of specifications such as B.S.1024 makes this possible.

These are the main points from a personal aspect. He had no figures available as to the efficiency of drying operations; most probably they would show thermal waste, but in many cases major alterations might be necessary before any notable reduction in fuel may be effected.

Authors' Reply

Points 1 and 2 which Mr. Arnott raises in connection with over-all fuel economy should receive particular emphasis. There is no doubt that the best method of attacking the problem is to check the ratio of total fuel used to unit weight of finished products and then make a serious effort to cut down this ratio. The ratio of the total metal melted to finished castings will constitute an important item in regard to the above.

FORCED-DRAFT CRUCIBLE FURNACES

MR. H. T. WINTERTON wrote that thanks are due to Mr. Frank Hudson and Mr. McRae Smith for their Paper on fuel conservation, with its particular aptitude at the present time, and one feels that the general recommendations, if carried out, should be of considerable value in the saving of fuel.

The part of the Paper on brass melting furnaces is primarily designed to help the many hundreds of small brass shops, many of whom still use the most uneconomic method of all, namely, the natural-draft furnace. It seems a pity, therefore, that Table II, which was compiled for a Paper given in 1928, should be used for comparisons of times and production costs.

The figures given for the forced-draft crucible furnace are surely not comparable with modern standard practice. The melting time for a 400-lb. pot should be more nearly in the region of 1.00 hr., and at a modern ratio of 1.7 the fuel cost should be about 10s. and not 16s., using a hard Durham coke. In the natural-draft furnace, even using a 1.2 coke ratio, which is high for small shops, the fuel cost would be at least 25s. per ton. These considerable differences, if stressed, would be likely to convince the non-ferrous shop owner of the advantages of using modern tackle, and a very considerable saving in fuel would accrue.

Another point mentioned in the Paper which might be elaborated, is the system of allowing each man to melt his own metal. This is very common, and is most wasteful both of fuel and time. Should this practice be continued after an economic plant is put in, it leads, not only to waste of fuel, but stewing of metal, with consequent deterioration of casting quality.

For the small pots of 80 to 120 lb. capacity, which are in very common use, a high-speed furnace shows some extraordinary reductions in fuel consumption as against some of the old pit furnaces still in use. In one such pit recently replaced, the coke consumption was reduced by four-fifths, and the time of first melt reduced from 90 mins. to 35 mins., from cold. These particular figures may be unusual, but give some indication of the wastage of fuel occurring at a time when every ton is precious.

One often hears the remark that "we are so busy now we have no time to go into figures," yet a little time devoted to this subject would probably result in very great saving, both of time and fuel.

Authors' Reply

Following Mr. Winterton's remarks, the authors feel that it might be useful to correct the impression that all natural-draft crucible furnaces are most uneconomical melting units. This is by no means so in all cases. If a large enough stack is provided, and there are instances where some foundries have utilised an obsolete power house stack, a draft nearly equal to that obtainable from forced draft can obviously be obtained. Furthermore, should the above coincide with the use of large crucibles, say, of 400 lbs. capacity, a fuel to metal ratio approaching 1:5 can be obtained. Admittedly, however, the majority of natural-draft, and many forced-draft furnaces cannot come up to this standard, nor have hope of ever doing so, in view of the particular type of conditions existing. So far as fuel conservation is concerned, the comparison of fuel consumption of one type of furnace with another, without taking into account the many other factors involved, is distinctly misleading and the principal endeavour of the Paper is not to indicate the most efficient furnace, but rather to help the foundryman save fuel in foundry operation as a whole.

THE SKLENAR FURNACE

MR. W. WILLIAMS wrote:—Although the tables show a great superiority for the Sklenar type of reverberatory furnace, it should be noted that F. W. Rowe published these in 1924-25 and 1927-28.

Thus the figures are only concerned with the coke-fired type and do not in the least represent the better efficiency of these furnaces brought about by oil-firing and the noteworthy improvement in the design of the brickwork.

For instance, the present 1,000-lb. type melts the full charge of gunmetal to a temperature of not less than 1,225 deg. C. in 35 to 40 mins. This is done without any additional operational costs, apart from the transport of the charges and the removal of the molten metal. Ten heats in a 9½-hr. day is a very easy proposition. The fuel consumption on ten successive heats would never exceed 1 gall. of oil per 100 lbs. of metal melted. The lining, plus repairs, including the labour for such, costs approximately £40 for a lining life of not less than 600 heats, *i.e.*, 300 tons or less than 3s. per ton.

Again, metal losses have not been allowed for in Mr. Rowe's tables, although this is a considerable item of costs. Owing to the method of melting in the furnace throat, the metal then running on to an incandescent hearth, plus the complete control of the flame conditions, the losses in these Sklenar furnaces are not in excess of 0.75 per cent. for good quality gunmetal, *i.e.*, about half the losses experienced in the crucible types. For phosphor bronze the losses have proved to be down to even 0.25 per cent.

Further, if the 320-lb. capacity is considered, sixteen heats in a 10-hr. day is the regular output. The 1-ton oil-fired type furnace melts to 1,225 deg. C. minimum a full charge in 45 mins., with a consumption of 17 to 18 galls. of oil, for each succeeding heat, after the pre-heating.

To sum up, taking into consideration the lower number of heats obtained from crucibles nowadays, the operational costs of this type of furnace (all, excepting the actual metal) are about one-third of the most efficient types of crucible melting furnaces. Also, and this is the most important factor where high-duty (strength and homogeneity for pressure resisting) is required, the heating conditions of this type produces the superior quality.

The factor of reliability is a most important one in these days of striving after greater production, for there is never the failure to produce a charge of metal as happens when a crucible fails. Taking into consideration every aspect of fuel consumption it is a fair computation to say that the latest type has only a 50 per cent. consumption of the most efficient of the crucible types.

Authors' Reply

The authors have found Mr. Williams' outline on the performance of the Sklenar furnace of considerable interest. Undoubtedly this type of furnace has proved very successful in handling gunmetal and bronzes, but its use is limited on high-zinc alloys such as brass. One is a little sceptical of the statement made in connection with the comparison of melting losses, as the figure given is considerably greater than that experienced in normal crucible melting. Furthermore, one hesitates to accept that the particular melting conditions of the Sklenar furnace produce metal of superior quality over that obtained by crucible melting. With proper melting control, the crucible furnace is just as capable of producing metal equal in quality to that made in the Sklenar.

CUPOLA PRACTICE

MR. D. ROGERS wrote:—The authors of the Paper have not expressed any opinion on the relative merits of the single and double row of tuyeres. Is not the single row of tuyeres likely to be more economical? Given a single row of tuyeres of proper proportion and adequate air supply, the bed can be lower by as much as the distance between the two rows of tuyeres in the case where a double row is employed.

The writer would appreciate the authors' opinion on the distance between tuyeres and the charging sill. The writer is operating a cupola where this distance is 7 ft. and there is undoubtedly much heat lost. The authors have stated: "The bed made incandescent as soon as possible" and "After charging, as long a period as possible should be allowed for soaking." The writer is in agreement with the first statement, but suggests that the statement with regard to the soaking period is debatable, and suggests that a period of from 30 to 60 mins. is ample. A longer time is likely to give slightly dull iron, the coke having burnt too much and being dull when the blast is put on after a long stop.

The authors' views on a boshed lining would be appreciated, as it is an alteration that does not call for much expense. There is a great need for making smaller chill-cast pig-iron, but that is an alteration which cannot be made now. Chill-cast pig requires less coke to melt than sand-cast, but even less would be required were the pigs made smaller, like the Indian pig-iron. Some English chill-cast pigs weigh up to 160 lbs. each.

Author's Reply

As the Paper deals with fuel conservation rather than with cupola practice, the question of the comparative merits of a single row of tuyeres as compared with a double row of tuyeres has not been mentioned. The authors certainly agree that a single row of tuyeres will be more economical than a double row, provided the single row allows for an adequate air supply, because the bed can be lower by as much as the distance between the two rows of tuyeres. It certainly would be in the interests of fuel economy where possible to convert double row tuyere furnaces to a single row. To ensure that an adequate supply of air is available the single row should be opened out to give a tuyere ratio somewhere in the range of one-fifth to one-eighth of the effective melting area of the cupola.

This advice is given purely with a view to economising in the depth of bed required in a cupola with a double row of tuyeres and does not in any way take into account certain advantages which may accrue from the double row by giving greater control of air distribution in depth. It should be pointed out, however, that in a number of cupolas the so-called double row is merely a staggering of a single row, in which case it probably would not be worth while to make any alteration.

Distance Between Tuyeres and Charging Sill

The distance mentioned by Mr. Rogers, namely, 7 ft., is much too short, even in quite a small cupola. Unfortunately, a great many cupolas in this country suffer from this defect, the short distance between the top of the tuyeres and the charging sill being quite inadequate to enable advantage to be taken of the hot gases passing up the stack. In the authors' opinion this distance should not be less than 12 ft., and 15 to 18 ft. is advantageous. This dimension will not vary very much in different sizes of cupolas, because the underlying idea is to allow capacity for a reasonable number of charges to be contained in the cupola shaft and so absorb heat from the hot gases passing up through the charges.

Unfortunately in a great many cases this dimension has been restricted owing to the limitations of buildings and particularly the height of platforms. In many cases these defects could be very easily overcome.

Soaking Period

The question of the duration of the soaking period depends very largely on circumstances and the method of operation of the cupola. Perhaps the authors have not made their statement quite clear in regard to this as, under certain circumstances, a long soaking period may tend to give dull metal on account of too much of the bed coke having burned away.

The coke bed should be made up gradually and burned through until it becomes incandescent. This will take some considerable time and may vary between, say, one to three hours. During this period small additions of coke should be placed on the bed in order to make up for losses. If really hot metal is to be obtained from the first charges this procedure is essential in order to get the sand bottom and the refractory lining hot. Unless the cupola well is made really hot, and this can only be done by absorption of heat from the coke bed, then the first metal will be cold because it has to give up heat to carry out the work which should have been done previously by the incandescent coke bed. If this operation is carried out properly and the coke bed has been again made up to the requisite height immediately prior to charging, probably a period of one hour for soaking and preheating the metal charges will be adequate. In fact, it is agreed that in some cases this may be too long if there is a very strong natural draft through the cupola stack.

Views on a "Boshed" Lining

It is certainly agreed that a "boshed" lining will save coke in making up the bed. Where the base mixture being melted consists of cast iron, pig-iron, etc., of fairly uniform size and composition throughout the whole of a day's run, no difficulty should be experienced when using a "boshed" lining. However, if the charges, as is the case in the melting of steel mix cast iron, contain materials of very widely different composition, then a "boshed" lining has very considerable disadvantages and irregularity of composition in the final metal is likely to result.

It is agreed that it is very easy and inexpensive to convert a cupola from a straight lining to a "boshed" lining, and the melting rate need not be inferior if the restricted diameter is not carried very much above the top of the tuyeres. It should be emphasised, however, that where very close control of composition is required and where it is necessary to run a number of different compositions per day in comparatively small tonnages, then the saving in fuel by reason of a "boshed" lining might result in considerable loss of man-hours due to castings being outside specification limits, etc.

The authors thoroughly agree with Mr. Rogers' remarks about the necessity for having smaller chill-cast pig-iron. This should not present any great difficulty to chilled pig-iron manufacturers. A simple alteration to the design of the chill moulds in providing more and deeper notches to each individual pig should give the desired result. It is agreed with Mr. Rogers that chill-cast pig-iron, being free from sand, usually requires less coke to melt it than is the case with sand-cast pig-iron.

Scottish Branch—Falkirk Section **Paper No. 79**

The Use of X-Rays in the Foundry

By W. MONTGOMERY* (Associate Member)

During recent years there has been an ever-increasing number of Papers read before various technical and scientific societies on subjects relating to the application of X-rays in industry. Mostly, they have been concerned with technique, theory, and application from the viewpoint of the industrial radiologist. It is intended that this Paper will interest foundrymen and more particularly those who control moulders or who exercise technical control over foundry practice. All reference, therefore, to the wider field of industrial radiology, including the routine examination of welded steel vessels and structures will be omitted.

It is interesting to note that Röntgen, in his pioneer work, realised the value of the "Röntgen" rays in the examination of the gross structure of metals, although it was the medical faculty, and not the metallurgical fraternity, which gave the new tool its initial flying start.

Does the average foundryman realise what a valuable tool this can be? Too often it is regarded by craftsmen as a mysterious scientist's eye, which brings to light unimportant flaws in castings, which would be far better left shrouded in the limbo of the invisible, well below the metal surface, and beyond the ken of an ardent inspector! No idea could be more mistaken. The proper conception of works' radiographic control is that, with sympathetic technique and interpretation, hitherto unsuspected flaws may be located, and, moulding or melting practice having been reviewed, finally eliminated.

Simple Explanation of Theory

Everyone may not be potential owners, users, or operators of an X-ray equipment, but it is assumed that some day all engineers and foundrymen will be asked to handle, inspect, or offer an opinion on a radiograph, and for that reason it is deemed advisable to include in this Paper a simple, though probably sufficient, explanation of the underlying principles in the "gross structure" examination of metals.

X-rays are a form of radiant energy analogous to light rays and they obey the same laws of reflection, refraction and diffraction. The intrinsic difference is in their respective wave-lengths. The wave-length of light is about 5,000 Angstrom units at the centre of the visible spectrum, while X-rays vary in wave-length between 500 and 1A. This significant difference in wave-length between visible light rays and X-rays holds the explanation of the latter's ability to penetrate material opaque to ordinary light. It will be readily realised that any radiation having a wave-length approximately

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* Works Chemist and Metallurgist to Henry Balfour & Company Limited.

1,000 times less than that of ordinary light will slip past molecules of matter in much the same way as light darts through the interstices of a Venetian blind.

How X-rays are Produced

Essentially, this type of radiation is produced when the atoms of a heavy metal such as tungsten are bombarded with electrons. These electrons are units of negative electricity which rotate round the metallic nucleus in orbits as the planets round the solar system. In practice, free electrons are produced by heating to incandescence a filament at the cathode of a very highly-evacuated glass tube. These electrons are caused, by the application of high voltage, to impinge at very high velocities on the target or anode of the tube. The interference in the atomic arrangement of the metal composing the target, due to the impinging electrons, produces the radiation known as X-rays.

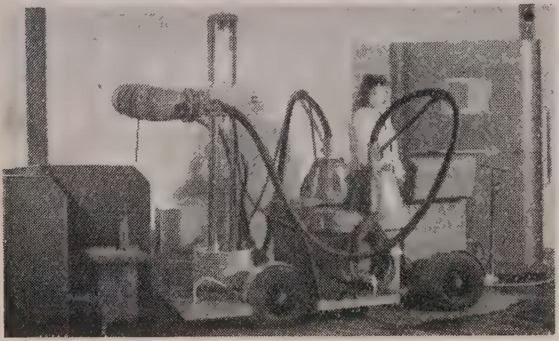

FIG. 1.—SIEMENS-SCHUCKERT X-RAY EQUIPMENT, RATED AT 250 KV. AND USED FOR THE EXAMINATION OF CASTINGS UP TO A METAL THICKNESS OF 3½ IN. OF STEEL OR IRON.

The wave-length of the rays decreases, and conversely their penetrative power increases, with increase in the exciting voltage. The potentials necessary for penetrating up to 5 in. of steel are of the order of 90,000 to 300,000 volts. These high potentials are obtained by stepping up the ordinary A.C. mains voltage by means of a transformer. The alternating current is made unidirectional by mechanical rectification or, as is more usual in modern equipments, by the use of thermionic valves. Of the total input of energy at the target of an X-ray tube, only a small proportion is converted to X-radiation—the remainder being dissipated as heat. This, as will be appreciated, necessitates the provision in the plant of some system of cooling to remove unwanted heat from the target material. If the tungsten anode became overheated, it would start radiating electrons, the current would flow in the opposite direction and lead to the rapid breakdown of the tube. Most tubes are water or oil cooled. For industrial purposes they are enclosed in a lead holder, or container with a small light-metal " window " to allow the passage of the rays in

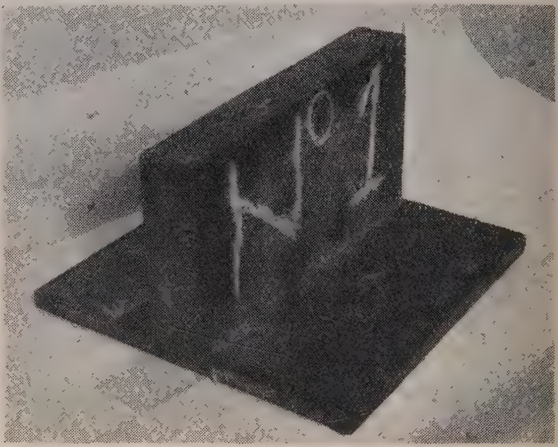

FIG. 2.—SHAPE OF TEST-PIECE.

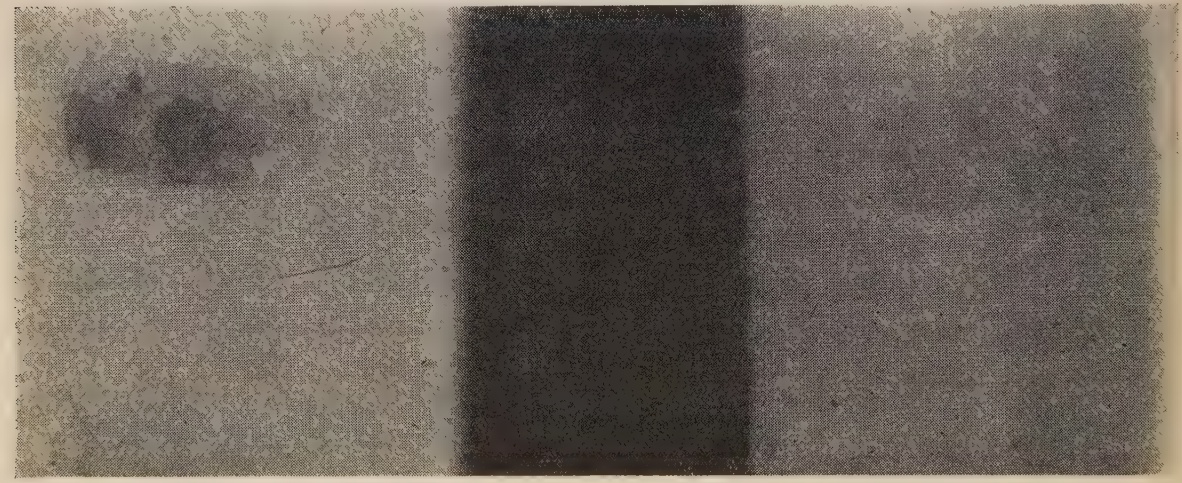

FIG. 3.—SECTION OF RADIOGRAPH OF COLD-POURED TEST-PIECE.

a controlled beam in one direction only at the will of the operator. Fig. 1 shows a typical equipment by Siemens-Schuckert, rated at 250 kV and used for the examination of castings up to a metal thickness of 3½ in. of steel or iron. It will be noted that the complete unit is self-contained, and, while it is ordinarily housed in a special test-room, it could, on occasion, be transported to any situation in the foundry where a primary A.C. source of current is available.

The fact that X-rays are actinic to photographic emulsions in the same way as visible light, makes their industrial application possible. Ordinary practice indicates that the film or plate be placed behind and as near the object as possible. The beam of rays, which for practical purposes is presumed to emanate from a point source, penetrates the object and the proportion of the original rays which emerges from the side remote from the tube affects the photographic emulsion on the film, which is, naturally, encased in a light-tight container. Thus, it will be understood, a point to point difference in density will be obtained on the film, after developing and fixing the silver salts in the emulsion, corresponding to differences in intensity in the X-ray beam as it emerges after traversing a solid object. Differences in thickness in the object will thus show on the film as variations in density. Similarly, a void such as a gas pocket within the wall thickness of a casting will appear on the X-ray film as a shadow of greater density than the adjoining flawless section of metal. An inclusion of greater opacity to the rays than the surrounding metal will naturally absorb more of the incident rays and show on the film as an area of less density. Flaws equal in magnitude to more than 1 or 2 per cent. of the cross-sectional thickness of the metal under examination are capable of detection.

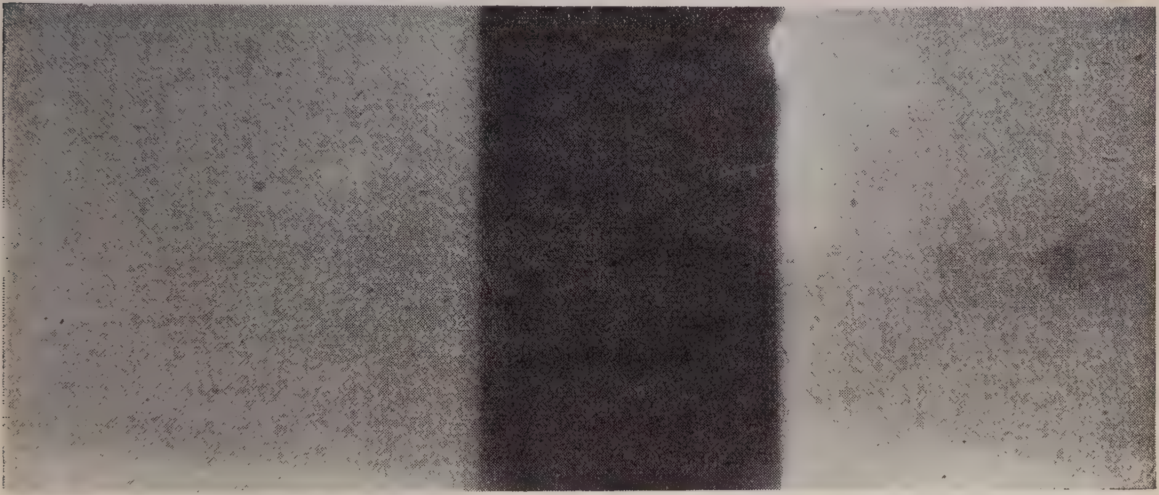

FIG. 4.—SECTION OF RADIOGRAPH OF HOT-POURED TEST-PIECE.

FIG. 5.—SHOWING FEATHERY APPEARANCE OF MAIN "SCABBED" AREA OF CASTING SHOWN IN FIG. 4.

Application to Castings

Before X-ray examination can become a useful instrument in castings inspection, foundrymen must establish an elastic criterion of acceptance or rejection. By this it is not suggested that a particular casting, having six blowholes instead of a maximum of three, should be rejected, but rather that it should be judged, by competent interpreters, with consideration for the size, type, amount, and position of the inclusions, taking into

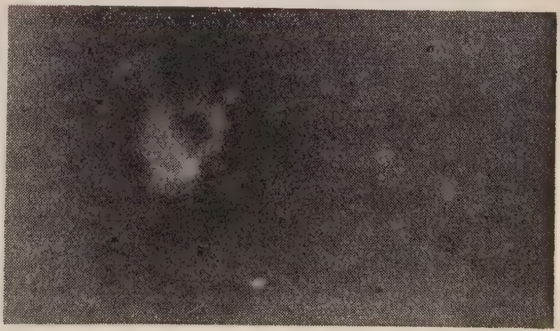

FIG. 6.—CASTING WITH TOP-HAT CHAPLET, SHOWING GAS TRAPPED WITHIN CHAPLET.

account the ultimate service which will be required of the finished casting.

The various types of flaws and inclusions which are discernible on a radiograph are shown in the accompanying illustrations. Although professional interpretation is a matter of experience in both radiology and moulding practice, a study of the pictures will allow any foundryman to give, at least, a knowledgeable interpretation to any radiograph. The only flaws likely to be found in castings are:—(1) Blowholes, gas holes and air pockets; (2) inclusions of foreign material, *e.g.*, sand, slag, ladle lining material, oxide, segregations of an insoluble secondary metal or even undissolved chaplets; (3) shrinkage cavities or draws; (4) porosity; (5) cold shuts and mis-runs, and (6) pipes and cracks.

It will be seen that the number of flaws to be found in any one casting is strictly limited but, unfortunately, the variety of forms which each shows on the radiograph is considerable. Happily, although no two shrinkage cavities display an exactly similar shape or outline, there is a particular disposition of the "shadows" in each case which leads the experienced eye to diagnose each correctly.

FIG. 7.—TEST CASTING POURED COLD SHOWING SHRINKAGE.

Experimental Data

Two synthetic specimens were first prepared. They took the form of T-shaped cast-iron webs, one section of which, in each case, was 2 in., while the base was ½ in. thick. A shrinkage defect or "draw" was certainly to be expected near the changes in section. One piece was cast very hot, while the other was poured with exceedingly sluggish metal. Before closing the moulds, a piece of ladle skimming was inserted in each to represent a state of affairs which could conceivably occur in practice if faulty pouring methods allowed a little dross or slag to enter the mould. In the hot-poured specimen was also included a stud chaplet, while a wet spot was made in the sand on the top part in the hope of inducing "scabbing." The cold-poured casting had a lead-coated stud chaplet inserted. It will be instructive to study the radiographs with particular regard to these conditions.

The shape of the test-piece, together with the position of the thick web, is shown in Fig. 2. Figs. 3 and 4 have been taken with the rays incident to the bases or thin sections, and thus offer a plan view through the castings.

In the cold-poured specimen (Fig. 3) it will be seen that little, if any, fusion has taken place at the chaplet cast-iron interface, and that round gas inclusions are near the chaplet. A small light inclusion near the chaplet indicates that a spot of molten lead has been carried by the primary stream of iron away from the coated chaplet and been trapped in the surrounding metal. The slag inclusion appears as a slightly elongated intense shadow of even outline. All slag inclusions, which incidentally are usually much smaller in normal production castings than is indicated by this deliberate inclusion, are invariably even in outline and often vary in shadow value throughout the image. Occluded gas often takes the form of small clusters of bead-like shadows, as is shown in the radiograph under examination. Steam "blows" from a damp mould often conjoin and the radiographic result is a gross shadow of even outline somewhat similar to the large slag inclusion discussed before. The essential difference is that gas tends to outcrop towards the upper surface of the mould in a pipe formation, often in the direction of the primary flow of metal in the mould.

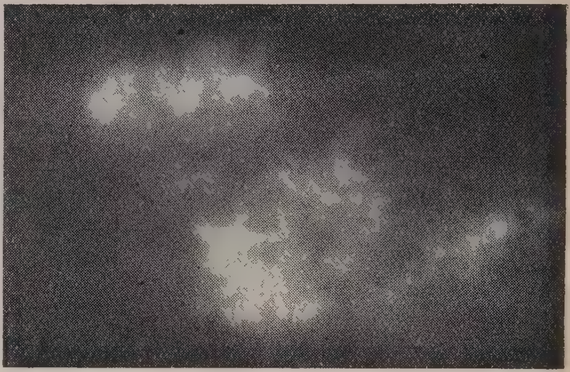

FIG. 8.—TEST CASTING POURED HOT SHOWING SHRINKAGE.

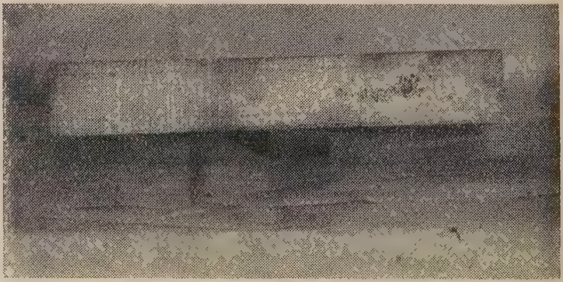

FIG. 9.—SECTION THROUGH DRAW.

Behaviour of Chaplets

In considering Fig. 4, the first noticeable feature is the absence of gaseous indication on the radiograph, going by the criteria established in the previous examination. This, of course, is in consequence of the higher pouring temperature. The chaplet, too, has fused more thoroughly in this case, although it is interesting to note that the ordinary tin coating has not diffused into the surrounding metal; this is shown by the patchy appearance of the chaplet shadow. The feathery areas are mostly sand inclusions.

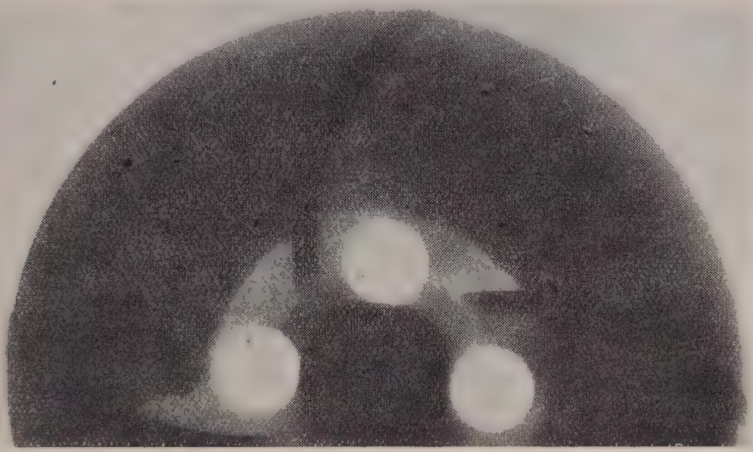
FIG. 10.—SECTION OF RADIOGRAPH SHOWING CRACKS IN CAST-IRON IMPELLER.

Fig. 5 shows the feathery appearance of the main "scabbed" area in this same casting. The scab was located at the base of the heavy web. This necessitated projecting the rays through the base of the web at an angle of 45 deg. to the base of the casting, and explains why one side of the resulting radiograph was so dense, while the image at the opposite edge was deliberately produced by the incidence of a wet patch on the mould surface.

It may be interesting to compare the behaviour of the chaplet in Fig. 6 with the previous two

This is a type commonly known in the trade as a "top-hat" chaplet. The radiograph shows that much better contact is obtained between this form and the parent metal, but that gas evolution still takes place.

Figs. 7 and 8 show the radiographic appearances of the shrinkage defects in the two castings. The filamentary form of the shadows is typical of this "draw" formation. When a casting exhibits this scattered void defect, it will be readily seen, from these pictures, how prone to weeping or leaking under a water pressure test it would be. There is notable difference between the hot- and cold-poured specimens. A section through the draw in the cold-poured casting is photographed in Fig. 9.

An Extra Variable

In a third casting similar in all respects, but one to the two test castings just discussed, and which was moulded from the same pattern, gated and poured under identical conditions, and made from metal of similar composition and

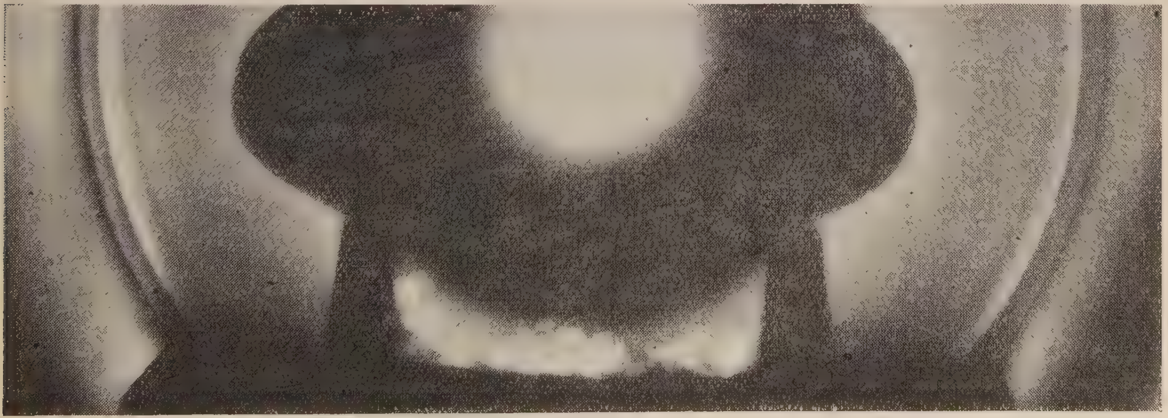
FIG. 11.—SECTION OF RADIOGRAPH OF PUMP CASING SHOWING SHRINKAGE CAVITY.

melted under similar conditions, the only outstanding difference was that a brand of machine-cast pig-iron, which formed part of the charges for the other two castings, was omitted. A remarkable difference was observed in the extent of the internal shrinkage, and it is suggested that, at least in this particular case, the inclusion of this brand of pig-iron contributes quite considerably to the tendency for drawing to occur.

Stress-Removal in Impeller Castings

Profit might result from examination of the impeller casting in Fig. 10. Cracks may be seen in the periphery, just at the junctions of the curved spokes with the body of the casting. It was suggested that these castings were flawed before they ever left the foundry, but radiological examination before and after the castings were commissioned soon elucidated the mystery. The indication was that casting stresses bound up in the metal, due to design difficulties, were relieved only by physical fracture after the castings were put into service in sulphuric-acid pumps. On this assumption, the impellers were all given a low-temperature stress-relieving anneal, and no further trouble has been experienced. Fig. 10 is interesting, in that the case history shows how X-rays can vindicate the foundryman on occasion.

A Faulty Pump Casting

Fig. 11 is a picture of a pump where an extremely bad shrinkage cavity shows at the base of a web cast on as a seating. The other round cavity indicates the presence of a steam or gas "blow." The seriousness of the shrinkage defect lay in the fact that all the castings which showed radiographic indications of shrinkage, leaked very badly at this spot. This illustration proves that radiographic examination can, in some cases, pay its way many times over by a very considerable saving in machining costs. As in this instance, alteration to pattern, or in gating methods, may be indicated.

The discussion on this particular defect might be enlarged as follows:—No sudden change of sectional thickness is indicated such as would naturally lead one to expect the incidence of shrinkage cavities in this location, and no ill-conceived moulding methods were employed. It is that type of defect caused by what is known in the literature as the "Léonard Effect," and has been the subject of investigations by Fletcher and others. Briefly, it may be said that overhanging cores and projecting parts of the mould which are partly surrounded by molten metal after filling the mould, become exceedingly hot, and in extreme cases the mould surface at that particular projection rapidly approaches the temperature of the molten iron. The resulting hot spot tends to hold the adjacent metal in a fluid or pasty state after the neighbouring parts have solidified. This is exactly what has occurred in the casting under examination. The cavity has formed just below a projecting wedge of sand which, to make matters worse, lies in the path of the primary flow of metal in the mould. In this case, there are two obvious remedies. The metal may be poured at a lower temperature, or iron sprigs may be inserted into the sand at the part in question with the object of conducting the heat away more quickly from the sand surface. The former expedient was tried with success, but, unfortunately, the lower pouring temperature gave rise to an epidemic of trapped dirt in another part of the casting. This was admittedly a tricky, but instructive problem, and finally a review of gating methods and metal composition gave satisfaction. For comparison, the radiograph of the doubtful area in a good casting is shown in Fig. 12.

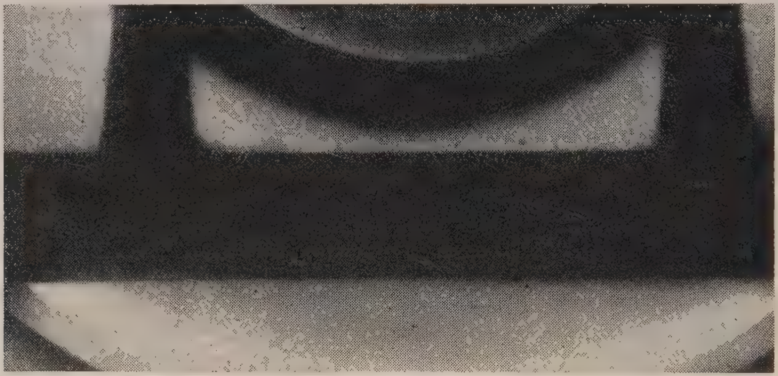

FIG. 12.—SECTION OF RADIOGRAPH OF GOOD SECTION OF PUMP CASING.

Aircraft Castings

Figs. 13 and 14 are included to show the value of this inspection method in the field of high-duty aircraft castings. Fig. 13 is of an aluminium casting with brass inserts; it appeared convincingly good on the basis of a superficial examination but, as will be seen, slight internal porosity in the region of the gate was disclosed by radiography. The casting was rejected on this evidence as it formed part of an important aircraft assembly.

Fig. 14 is the X-ray view of a die-cast aircraft component which showed marks of a suspicious character on the surface but, as is here shown, subsequent "internal" examination proved that the doubts were ill-founded. The marks were entirely surface irregularities that could be eradicated and nothing approximating to a crack existed. The casting was passed.

Foundry Investigational and Development Work

Difficulty had been experienced in the foundry with certain castings in copper-nickel. The trouble was due to the temporary lack of supplies of magnesium for deoxidising purposes, being unavailable from the usual pre-war source, and this state of affairs soon gave rise to the attendant faults which every foundryman will associate with insufficiently deoxidised metal. Various substitutes for magnesium were tried without success and, finally, the specific decided upon was manganese-boron. The experimental castings were all radiographed after treatment to determine the extent of their "inner cleanliness." Two of such castings are shown in Figs. 15A and 15B—the one which has not been deoxidised gives the usual radiographic indications of round gas inclusions while the other (deoxidised with manganese-boron) is much cleaner. Both show incipient shrinkage in the regions of the gates. The point to be brought out here is that, in the normal way, such investigation would prove rather tedious and costly, as each casting would have to be sectioned or machined and even then the information obtained would be much less complete than that gleaned from a few radiographs.

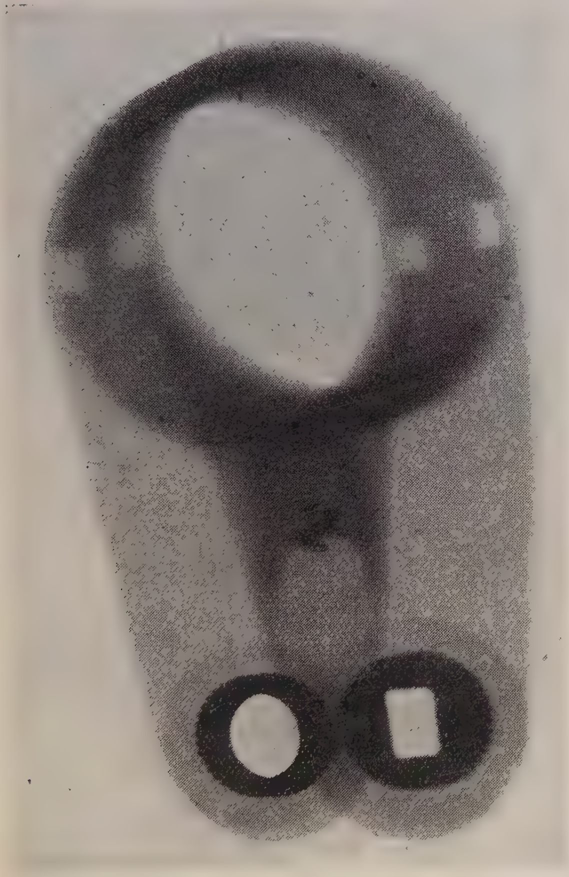

FIG. 13.—RADIOGRAPH OF ALUMINIUM ALLOY CASTING SHOWING POROSITY IN REGION OF GATE.

Vitreous Enamel Work

A good deal of experimental work has been done by the author on the application of refractory vitreous enamels to cast iron. This sphere of activity was more concerned with vessels and pipes which had to receive a chemically-resistant glass lining. While this might well be the subject of a separate Paper, one aspect of it embraced highly interesting radiographic results.

Over a period a technique had been developed for lining cast-iron pipe bends, straights and T-pieces with this highly resistant glass. At an early period in the development it had been observed that of all the failures there were some pipes which gave rise to vigorous and repeated "boiling" or bubbling after the enamel had fused, and of these latter castings some few gave no external indications as to the reason for this blistering, as the surface was unsullied and unscabbed. Many representative pipes were subjected, therefore, to X-ray examination and it was soon established that bad blistering was invariably accompanied by bad blowholes within the walls of the castings concerned. Figs. 16 and 17 are illustrative of a good pipe and a badly-flawed one respectively. The round gas inclusions showing on the latter radiograph are fairly representative of the enamel blistering variety and, thus, the genesis of one cause of enamelling trouble is probed in an illuminating manner by radiography.

From the above, one might well deduce interesting points in agreement with the theory of gaseous inclusion and hydrogen diffusion in cast iron put forward in 1940 by Zapffe and Sims in a Paper* read before the American Ceramic Society.

Aiding Mould Assembly

The radiograph (Fig. 18) shows the use to which X-rays may be put in the examination of mould and core assemblies in the moulding shop. It has been claimed that the accurate positioning of cores in complicated assemblies can be greatly facilitated by means of shadow pictures such as this, but the author has never found it expedient or economical to recommend such a method. When a mould does offer the possibilities of radiographic positioning of cores, it is usually found that the old orthodox methods are infinitely more speedy and easy. The method has proved very helpful as a medium of instruction in the teaching of this branch of foundry practice. The example shown here has been taken through the closed mould of a simple bush casting and the position of the centre core can be clearly seen. The more transparent spots in the picture of the mould material indicate the presence of small flakes of a denser substance dispersed through the sand. In reality, these were oxide flakes and lumps of insufficiently-milled sand.

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* "Foundry Trade Journal," Oct. 3, Nov. 7, Dec. 5, 1940, and Jan. 2, Feb. 6 and March 6, 1941.

Interpretation

In a general way, it might be wise to point out some intrinsic differences in the technique of radiographing iron as opposed to—say—magnesium. Frequently, aluminium or magnesium castings exhibit intercrystalline cracking and micro-porosity, and these defects will only show on the film when processed by a careful and experienced operator. Often the only indication of micro-porosity on the film will be the incidence of a hazy, slightly denser area, very easily confused with the shadows caused by slight undulations on the surface of the casting. Intercrystalline cracks rarely lend themselves to radiographic record; it might well be imagined that a material could conceivably pass the X-ray department's test and ultimately fail in the microscopic and mechanical tests. Such does sometimes prove to be the case, but conversely an "X-ray reject" is never accepted by any other searching test. If a doubtful area is suggested by a radiograph, the radiologist should take two, three, or more "shots" of that area from varying angles, and thus obtain sufficient information to make a definite diagnosis. Particularly is this necessary where a crack is suspected. The appearance of a crack shadow is deceptively similar to that of a small pipe with the important exception that, on radiographing the former from various angles, the shape of the resultant shadow on the films varies with each exposure. The reason is that a crack is nearly two-dimensional, whereas a pipe is often of a cylindrical shape.

Fig. 19 is the radiographic picture of an electric-fusion cast-iron weld. The lead wires merely serve to locate the weld position. The contraction of the plates, on cooling, has given rise to a very bad crack at the centre of the weld deposit. The liability of the material to show contraction cracks is the one great disadvantage in the fusion welding of cast iron.

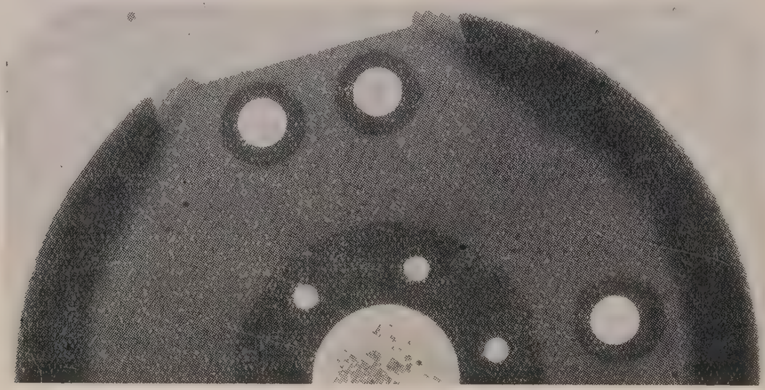

FIG. 14.—SECTION OF RADIOGRAPH OF A DIE-CAST AIRCRAFT COMPONENT.

Position of Flaws

Sometimes it is desired to locate the exact position and extension of a flaw within the wall of a casting. To answer these questions, a double exposure technique is used. The first exposure is made with the focal spot at a measured distance from the film, and the second exposure taken with the same focal-film distance but with the relative position of the tube changed so that the focal spot is in a different situation. A double record will be obtained in which the displacement of each spot will be proportional to the distance of the flaw in

FIG. 15A.—RADIOGRAPH OF COPPER-NICKEL CASTING NOT USING BORON AS A DEOXIDISER.

FIG. 15B.—RADIOGRAPH OF COPPER-NICKEL CASTING SHOWING EFFECT OF USE OF BORON AS A DEOXIDISER.

the object from the film, according to the following relation:—

$$x = h\,\frac{b}{a+b}$$

where x = distance of flaw from film,
h = distance of film from focal spot,
b = displacement of flaw,
a = displacement of focal spot of X-ray tube.

The same principle may be applied to determine the thickness of a casting wall when it is inaccessible. The usefulness of the method may be considerable if it is desired to discover, for instance, how far corrosion of the bottom of a cast-iron pot has progressed.

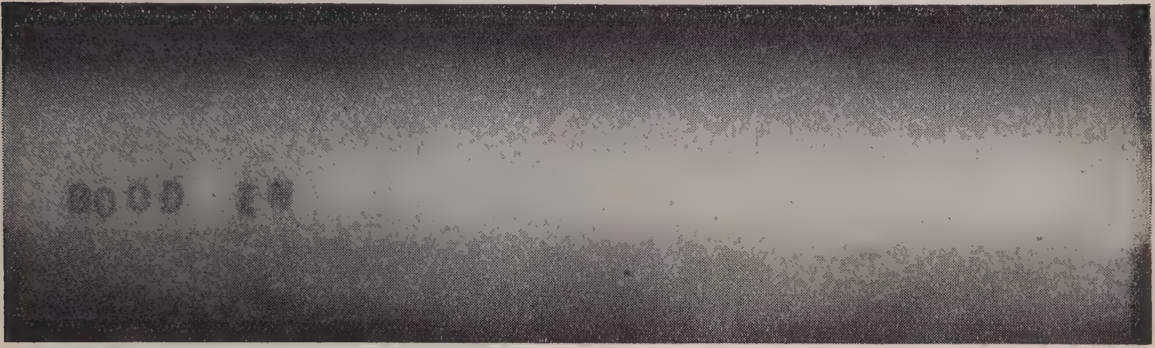

FIG. 16.—RADIOGRAPH OF GOOD ENAMELLED CAST- IRON PIPE.

Many ancillary uses for the equipment could no doubt be made by an interested foundryman. Samples of coke might be radiographed and compared with a standard to determine the degree of cellular denseness. Blacking might be jigged in an opaque container and examined under the fluoroscopic screen to give indications of the amount of coal dust present. Timber and plywood for patterns of special descriptions could, with benefit, be screened to expose knots and discontinuities before cutting. The author has, profitably, examined welded foundry cranehooks and slinghooks before commissioning them, and disclosed sub-surface defects of a highly undesirable character in equipment which, in fracturing, might have had consequences of a most serious nature.

Fluoroscopy

Brief reference has been made to the fluorescent screen; it must be said that the screen has very little value in the examination of iron and steel castings, but that for the light alloys it offers a rapid method of mass and routine inspection.

The materials used in the screens for transforming the absorbed energy into visible light are usually calcium tungstate and zinc silicate. The intensity of the rays, after passing through a solid of varying density, is proportional to the luminescence shown on the screen. Unfortunately, even under the most favourable conditions the sensitivity of fluoroscopic examination is somewhat poor, and even in viewing magnesium small porosity is often missed. Cavities under about 10 per cent. of the total thickness of the section being screened are quite likely to escape detection. It would be beyond the scope of this Paper to mention at any length the finer points of radiographic technique and the "tricks of the trade" which the professional radiologist might have recourse to. It might be mentioned, in passing, that the use of grids to absorb scattered radiation, stereoscopic

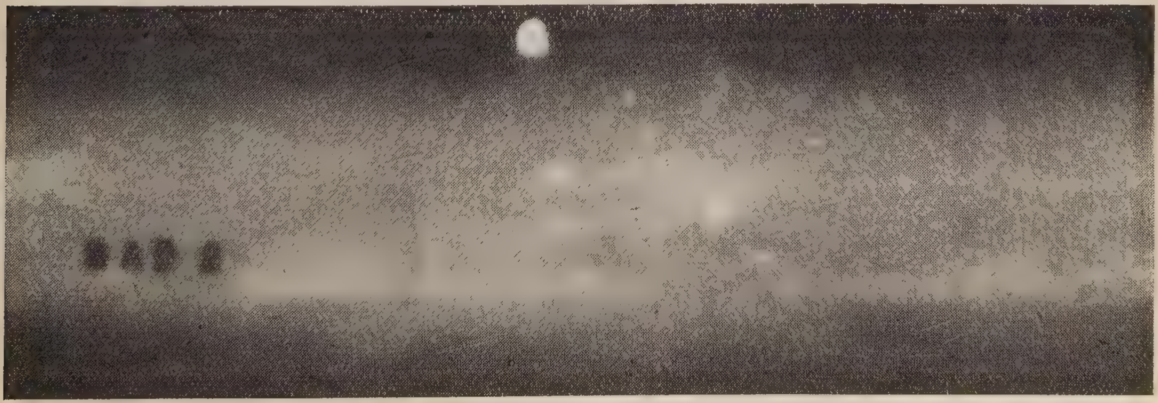

FIG. 17.—RADIOGRAPH OF BADLY-FLAWED ENAMELLED CAST-IRON PIPE.

methods of giving radiographs a three-dimensional perspective, and the clever method of showing in detail flaws in one plane or stratum of an object while blurring out all faults in every other plane, called tomography, are collectively of purely scientific interest.

The use of radium emanations in radiography is also purposely omitted, although the author considers that radio-active materials will be harnessed to this purpose more in the future than they are to-day.

Safety Precautions

It might not be amiss if some reference was made to the physiological effects of X-rays for the benefit of prospective purchasers of equipment. Modern tubes are well insulated, protected, and well-nigh foolproof, but still provision must be made for the protection of personnel. One particular effect of X-rays is that they ionise the air in the vicinity of the tube; hence it is very desirable to have adequate ventilation. This removes any unwelcome vapours which might possibly be present as well as removing any danger of short circuits.

X-rays adversely effect human tissue and, these effects being cumulative, the operators should not be permitted to work for extended periods in close proximity to the radiating tube. The reputable firms which instal these equipments always point out the dangers and advise as to the best methods of equipping the proposed laboratory.

If the use of X-ray equipment in the foundry is confined solely to the inspection department, then its capabilities as an engineering tool are being neglected. The fact must be borne in mind that X-ray examination is the only reliable non-destructive test for metals in existence. The following hypothetical case might illustrate this point: Let it be supposed that in a foundry possessing such equipment an entirely new production line is being considered. Taking for granted that the combined planning of designer, patternmaker and moulder has resulted in what is thought to be a feasible mode of attack, two or three test castings should be made in accordance with the design adopted, and each of these systematically radiographed.

The positions of recurring flaws should be noted: their nature, distribution and probable causes commented upon (in co-operation with the foreman moulder) and steps taken to adjust the methods of production or to alter the design in order to circumvent these pitfalls in the castings which follow up. Very often no alterations are necessary. Sometimes several pilot castings are produced before things settle into a normal run, but whichever happens to be the case, it can be safely taken for granted that time is saved, much scrap avoided, and considerable waste eliminated from machining costs.

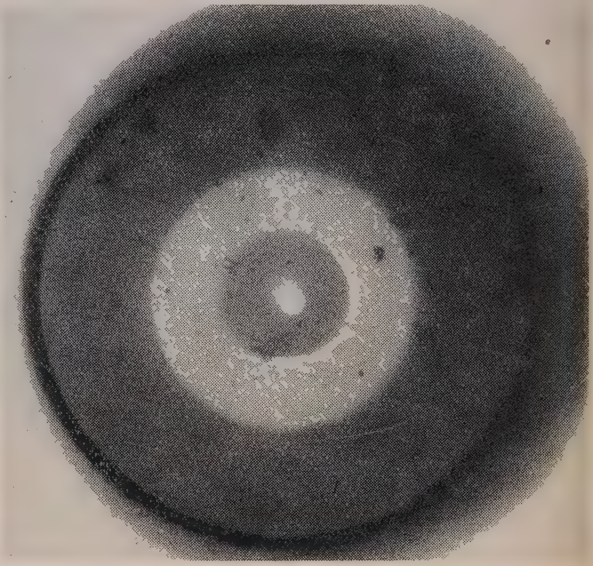

FIG. 18.—USE OF X-RAYS FOR EXAMINING MOULD AND CORE ASSEMBLIES IN THE MOULDING SHOP.

Conclusion

In attempting to stress the known and potential foundry applications of radiography, it will be appreciated that many interesting and important

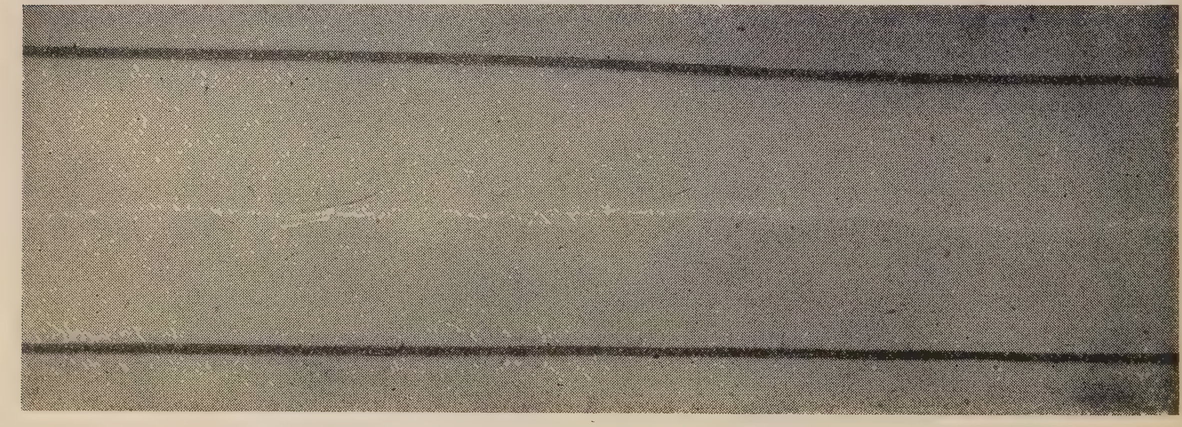

FIG. 19.—RADIOGRAPH OF A CRACK IN AN ELECTRIC-FUSION CAST-IRON WELD.

developments in other fields have necessarily been given scant mention. It is a branch of applied science which is as yet barely past its teething stage, although anyone interested will find that a considerable amount of literature has been written on the subject.

Again, consider what a potential sales argument in favour of foundry products a radiograph or two can be. The prospective customer is often quite unimpressed by talk of 20 tons tensile in a cast iron. To him, no benefit accrues by loading an iron with expensive alloys unless he can be reasonably sure that he is buying an internally sound casting. This is particularly true in these days of high-duty-iron specifications, and, no doubt, is an impeding factor in the substitution of iron castings of recognised physical characteristics for more expensive fabricated parts.

Although the perfect casting may be as unobtainable as the "philosopher's stone," it is neither impossible nor difficult to attain absolute soundness in important or highly stressed sections of the individual casting, if intelligent foundry control, aided and abetted by radiography, is practised. Added confidence could be placed in castings as engineering materials, and this, naturally, would reflect favourably on the foundry industry as a whole.

Finally, the author records his thanks to Mr. W. Lindsay Burns, managing director of Henry Balfour & Company, Limited, Leven, for permission to read this Paper, and publicly acknowledges his indebtedness to him for the keen interest he takes in industrial science.

South African Branch

Paper No. 791

Reclamation of Non-Ferrous Scrap Metals and Alloys on the South African Railways

By A. B. SIDEY*

It is necessary in a Paper of this description to touch on the history of the present reclamation plant and how it came to be established. Prior to 1930, the only reclamation of non-ferrous metals which took place was confined to that of small quantities of scrap C80 and L83 white metal. C80 white metal is a lead base magnolia-white metal for carriage and wagon bearings. L83 is a tin base white metal used for locomotive purposes. The process consisted simply of melting the metals in 30-cwt. cast-iron pots, fluxing them with salammoniac, and subsequently analysing samples. L83, on being analysed, always contained lead, due to contamination with C80 metal during the operation of recovery of the white metal scrap from old castings. In order to reduce this undesirable lead content as much as possible, treatment by the addition of tin, antimony and copper was resorted to. Even then, it was not considered good enough for locomotives, and was cast into ingots marked "S.H.L.," *i.e.*, second-hand locomotive metal, and used for tender bearings. This, then, was the extent of white metal reclamation in those days. The usual brass-foundry practice of utilising scrap brass and scrap copper was, of course, carried out, this being general practice. The value of using ingot metal with a known content had not yet become recognised.

Towards the end of 1930, the General Manager of the South African Railways ordered an investigation into the re-use of white metal in an endeavour to make an economy in the use of virgin metals. Experiments were conducted in the brass foundry, Pretoria, with which the author was associated along with Mr. G. Fenwick, of the headquarters offices of the company. Briefly, the experiments culminated in introducing compressed air into the metal by means of a pipe with a coil at the bottom into which $\frac{3}{16}$-in. dia. holes had been drilled. The coil was placed at the bottom of the pot and the air blown through the metal. This had the effect of removing all dirt and frictional matter in the scrap, but had rather a scouring action on the metal. To counteract this scouring effect, dry steam was introduced in the same manner as the air, *i.e.*, by means of a coiled pipe, the coil being inserted into the molten metal and allowed to remain at the bottom of the melting pot during the steaming operation.

This process gave the metal a close even grain with no oxide inclusions. Samples of the metal were periodically sent to the laboratory for analyses, but no advantage was taken at this stage of the figures supplied in order to bring the metal to a definite specification. It was, however, decided to test the metal on a practical basis and to this end the big-end bearings of a 16th-class locomotive were metalled with scrap metal which had been treated as stated. The metal stood up to the test in spite of the fact that it contained a good proportion of lead, whereas the specification for locomotive white metal did not permit of lead, and had to be 83 per cent. tin, 11 per cent. antimony and 6 per cent. copper. After this test many tons of metal treated in the above-mentioned way were issued and appeared to be giving satisfaction, as no complaints were received. In the meantime, extensive savings were being effected due to the fact that no tin was being used in the manufacture of locomotive white metal.

It was felt, however, that this "hit-and-miss" method of sending out metal for use without knowing its composition was one that could not continue for long with any degree of success. As lead was the only impurity showing in the scrap, as revealed by the analysis of samples submitted to the laboratory, fifteen different test-pieces of white metal were cast for experimental purposes, containing a lead content varying from nil to 15 per cent. These were sent to the laboratory and were subjected to various tests in order to determine the maximum percentage lead content which could safely be allowed in reclaimed locomotive white metal. As a result of these tests, which were conducted by Mr. (now Dr.) Leemann, the Administration decided on a maximum lead content of 10 per cent., the tin content to be 74.6 per cent., antimony 10 per cent., and copper 5.4 per cent.

It will be observed that the immediate saving in tin alone as a result of this policy was 8.4 per cent., and, when it is remembered that the production of reclaimed L83 white metal in the first five years from March, 1932, totalled 3,249,734 lbs., and has been considerably increased each year since, the savings have been very considerable on this item alone.

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* South African Railways and Harbours Board.

The Reclamation Plant

In 1932 it was decided to establish a plant for the reclamation, principally of white metal. The plant then consisted of three pot furnaces for dealing with white metal. One "Morgan" tilting furnace, with provision for one other, and a pit furnace. These latter three furnaces were allocated as follows: One for the melting of copper and antimony for the blending and manufacture of reclaimed white metal, and the two others for the manufacture of metallic packing or copper alloy.

A furnace built on the lines of a reverberatory furnace was included in the plant for dealing with mixed brass and white metal turnings, which unfortunately proved a failure for this purpose. In the separation of white metal turnings from brass turnings it is essential that the white metal should leave the furnace the moment it reaches melting point, and as this had not been provided for, the result was that the white metal "tinned" itself to the brass turnings, thus rendering the brass useless due to the high amount of white metal absorbed in the brass. It was later discovered, however, that this furnace, being designed for low temperatures, was suitable for reclaiming white metal from dross or skimmings, and it is now used exclusively for this purpose.

There was also a reverberatory furnace for dealing with brass turnings, scrap brass, or copper. This was the total furnace capacity when the plant commenced operations in March, 1932. Since then, however, three more reverberatory furnaces have been added for dealing with brass turnings and scrap and for manufacturing "B.M.," "F.M." and "A.B." brass. The specifications for these alloys will be dealt with later.

Reclamation of White Metals

All three white metals, that is, L83, C80 and P80, are treated in exactly the same manner for cleaning and refining. The scrap is placed in a cast-iron pot of 3,000-lb. capacity. In melting the scrap in the case of L83, the temperature is controlled to approximately 300 deg. C., and in the case of C80 and P80 to approximately 350 deg. C. Immersion pyrometers are provided to check the temperatures, but as the operator gains experience it is seldom necessary to use the pyrometer. The time taken to melt 3,000 lbs. of white metal scrap is approximately 45 min. After the metal has reached the molten state, compressed air is blown through it for 15 min. The sludge or scum which ensues is then skimmed off by means of a ladle perforated with holes $\frac{1}{8}$ in. dia. This design of skimming ladle allows virtually all the metal to percolate through, thus leaving what practically amounts to dross. This dross is laid aside and later treated for the extraction of whatever metal remains therein. The metal is now ready for the steaming process, steam being blown through the metal for 15 mins. The metal is then fluxed with "Astra" lead-tin-flux, one ounce of flux being used to every hundred pounds of metal. The flux is applied by sprinkling it over the top of the metal. It is allowed to stand for one minute and then stirred well in. The resultant residue or dross is removed and the metal poured into ingot moulds by means of hand ladles. After allowing the metal sufficient time to cool, the ingots are removed from the moulds and stacked, each melt being given a different sample number. A sample of each melt is taken and sent to the laboratory for analysis. On receipt of the analysis from the laboratory it is generally found that the metal is not up to the Administration's specification, in which case, after calculating the amounts of new metals necessary to bring the scrap metal to the desired specification, it is again melted and the necessary new metals added, after which the finished metal is poured into ingot moulds marked L83 or C80 as the case may be and sent to the Stores Department for despatch to depots throughout the Union.

It may be stated here that all C80 white metal manufactured since 1932 has been reclaimed metal. Due to the tin content in C80 white metal scrap always being in excess of 5 per cent., it has not been necessary to use any virgin tin whatsoever during the past ten years. This is a fact which is often lost sight of when considering the scarcity of L83 scrap as against the comparative abundance of C80 scrap. A factor which the plant had to contend with in the early stages was the high lead content in L83 scrap. At one particular centre the percentage of lead went as high as 47.6. From observation of the analysis of the metal from various centres it was obvious that little or no care was being exercised in recovering the white metal from bearings, axle boxes, etc. Representations were made on the matter, pointing out the Pretoria method of distinguishing the difference between tin base metal, which is hard, and lead base metal, which is soft. The Administration's specification for carriage and wagon white metal and white metal piston packing, known as C80 and P80 respectively, is lead 80, antimony 15 and tin 5 per cent., whereas the specification for reclaimed locomotive white metal is tin 74.6, antimony 10, lead 10, and copper 5.4 per cent. It will thus be readily appreciated that there is a divergence in the hardness of the two alloys.

The Pretoria Method

The Pretoria method is as follows: Each casting containing white metal is scraped with a piece of steel to ascertain which is soft and which is hard. In this way the castings are sorted into two heaps, and one day is allocated to hard metal and the next to soft, and so on. It is impossible to state whether the Pretoria method of distinguishing between the two metals was adopted generally, but in any case it is pleasing to note that there is now very little to complain of with regard to the mixing of the two metals. Some years ago the Administration issued an instruction that all scrap white metal ingots had to be stamped with the initial letters of the depot or origin. This instruction has had a good effect, and in addition allows the reclamation plant to keep a definite check on the standard of care exercised by the various depots in the recovery of the two white metals.

The type of furnace used in Pretoria for the recovery of scrap white metals from old castings is extremely simple in design. It is a cast-iron plate, laid at an incline, with brickwork around the plate. Formerly, boiler plate was used, but as warping took place it proved unsuitable for the purpose. The fireplace is so designed that the flame from the fire strikes the underside of the plate. The castings are placed on the plate, and as soon as the temperature reaches the melting point of white metal, the white metal runs off into a ladle conveniently placed to receive it. It is then hand-ladled into ingot moulds, so lettered to indicate that it is scrap white metal. With axle boxes it is necessary to burn wood on the top of the plate, the flames from the wood supplying the necessary heat to cause melting to take place. Whilst the furnace may appear rather crude for design, it has the virtue that it is impossible to overheat the metal, a factor which makes the process of reclamation much easier than it would otherwise be. Furthermore, the labourer operating the furnace has no need to worry about temperature control.

Another Source of White Metal Scrap

Another source of obtaining white metal scrap is through treating skimmings or dross derived from the metalling pots in the various workshops and running sheds. If all depots and workshops would keep L83 dross or skimmings separate from C80, then it is possible to deal with the material separately at Pretoria, but as a rule this does not appear possible, as, invariably, the resultant white metal is high in lead. This means that more tin is used in rectifying the composition than would be necessary were the drosses kept apart. It would assist if it were possible to keep this material separate and clearly marked as L83 or C80, as the case may be. This material has the appearance of dirt or sand, and to the uninitiated may appear of little value and possibly may at times be dumped on the ash heap. When it is remembered that up to 50 per cent. of metal has been extracted from this material it will be realised how important it is to the Administration that great care should be taken to ensure that it is not mixed or thrown away. The furnace for reclaiming the white metal from dross is built on the reverberatory principle, with a pyrometer built into the furnace. The operator attending to this furnace maintains a temperature equal to the melting point of the particular white metal which he may be reclaiming.

Treatment of Dross

The method of treating this dross, for the extraction of metal, is as follows. When the furnace has reached the required temperature, the material is charged into the furnace and spread over the furnace floor to a depth of about 3 in. by means of a rake. A flux is then thrown on top of the material and raked well into it. The material is then constantly agitated by raking, which causes the metal to leave the dross and flow out of the tap hole of the furnace. The tap hole remains open all the time, in order to prevent oxidation, which would occur if the tap hole was blocked and only opened at intervals. As the metal flows out at the tap hole it runs into ingot moulds, which are placed on a set of rollers, thus allowing the operator easily to move the ingot moulds along as each mould fills with metal. From there the metal is transported to the refining pots, where it is treated in the manner as outlined for white metal scrap. After this operation has been completed, a residue results, and as this residue has a definite metallic content varying between 30 and 55 per cent., further treatment is resorted to. The furnace door is sealed, including the tapping hole, in order to provide as near as possible a reducing atmosphere.

The residue or metal ash, as it has come to be known, is then mixed with " Astra Reco Flux " and powdered anthracite coal in the following proportions: 50 lbs. metal ash to 2 lbs. " Astra Reco Flux " and 4 lbs. of powdered anthracite coal. This mixture is then loaded into the furnace, the charge being approximately 1,000 lbs. The working temperature is 1,150 deg. C., and the operation is completed within three hours. The first tapping takes place within 45 min. and releases the white metal with the higher tin content (usually over 60 per cent.). The tap hole is again sealed, and the remaining material thoroughly stirred with a rake, before again sealing the furnace door. The same temperature is maintained for the remainder of the operation, when the final tapping takes place, thus releasing whatever metal remains. The second tap naturally produces metal of a lower quality than that of the first, but it nevertheless contains valuable tin, antimony, lead and copper. Refining then takes place in the refining pots in the manner already outlined, and the metal, after analysis, is blended by the addition of virgin metals to bring it to the Administration's specification.

Reclamation and Manufacture of Metallic Packing

There are two varieties of metallic packing used by the South African Railways, the one being a lead base metal consisting of lead 80, antimony 15 and tin 5 per cent., known as P80, which is used for engines using saturated steam, the other being a mixture of lead and copper in the proportion of 66 per cent. lead to 33 per cent. copper, with the addition of 1 per cent. sulphur, and known as P66, the latter mixture being used for engines using super-heated steam. The purpose of the sulphur used in this mixture is to amalgamate the two metals, and this it readily accomplishes due to the affinity which copper and lead have for sulphur. Without an amalgamating agent it would be virtually impossible to unite the copper and lead, as segregation would definitely commence as the metal is cooling. Even as it is, a small amount of segregation does take place, but is counteracted by adding a small addition of lead to the crucible, just before casting. Virtually none of the sulphur remains in the metal.

The reclamation of white metal P80 packing, is a comparatively simple matter. All white metal metallic packing turnings and bush ends are returned to the reclamation plant, melted down and cast into bushes of various sizes, to suit the different classes of engines. The moulds used are permanent moulds, made of cast iron, and where it is necessary for the bush to have a core, an iron mandril is used. Flour or talc powder mixed into a paste is used as a dressing for the moulds.

Care has to be exercised, when using white metal metallic packing turnings, by making sure that no contamination has taken place with L83 turnings. If contamination has taken place, then it is absolutely necessary that the metal should be analysed. Should the supply of P80 white metal turnings be insufficient to meet demands for bushes, all that is done is that C80 metal is used, both alloys being exactly similar in composition.

With P66 copper-alloy turnings a different position arises should contamination with white metal take place. The antimony and tin in the white metal would definitely make the metallic packing brittle, and therefore totally unfit for use.

The South African Railways, Mechanical Department, is a vast organisation and naturally, in the matter of piston packing for superheated steam, the advantages of complete manufacture and distribution from one particular centre are manifold, when coupled with the reclamation of the turnings or swarf which naturally follows in the manufacture of this material. If instead of the packing rings being machined at one centre, the bush castings are distributed to other centres for machining, it would follow that the resultant turnings or swarf returning to the reclamation plant would prove to be contaminated with other foreign metals such as brass, white metal, aluminium, etc., thus making reclamation a difficult and costly business. Even if the utmost care is taken to see that no contamination does take place, the problem of oxidation arises. Turnings or swarf arriving back, particularly from the coastal centres, would invariably be thoroughly oxidised, as it is the author's experience that this type of swarf, being coated with the cutting compound during machining, and its particular composition of lead and copper having a strong affinity for oxygen, becomes readily oxidised when exposed to the atmosphere. This does not only mean that waste would take place, but in attempting to reduce the oxides in the crucible, the life of the crucible is reduced by almost 50 per cent., due to the chemical reaction set up by the oxides. The attack on the crucible takes place at the level of the metal when it reaches the molten state and continues while melting to the required temperature is proceeding. Skimming can be resorted to while melting proceeds, but has little effect in minimising the damage being caused to the crucible.

With regard to the reclamation, manufacture, and distribution of metallic packing, complete manufacture at Pretoria suits the reclamation plant admirably. The castings are taken from the reclamation plant to the Pretoria machine shop, where the packing rings are machined for the whole Union, on one or two special machines. These machines are provided with a box, which fits close to the back of the machine, into which the turnings are placed, as they are cut from the bush casting. Absolutely no contamination with other metals can happen, as the turnings are not allowed to reach the machine-shop floor. The result of this policy is, that the turnings are transported direct to the reclamation plant, melted, and again cast into bush castings. No analysing is necessary, and only a bare minimum of copper and lead is used for the purpose of augmenting any deficiency experienced, when the supply of turnings proves inadequate. The cost of metal to the Administration is, in this manner, kept very low. The mould dressing for copper alloy is crude oil mixed with plumbago. Lard oil is also a good dressing. It is applied to the face of the mould with a cotton waste swab. Other dressings were experimented with, but the above has proved the most satisfactory.

Reclamation of Brass Turnings and Manufacture of Brass Ingots

For the reclamation of brass turnings reverberatory furnaces are used, of which there are at present four in the plant. Three furnaces are continually in operation, the fourth being kept as a spare furnace. The spare furnace is of great assistance in keeping down maintenance costs, in that any particular furnace showing signs of wear in the brick lining can be immediately attended to, and by lighting up the spare furnace no diminution in output takes place.

The first operation in dealing with brass turnings is to remove all iron and steel. This is accomplished by means of magnetic separators, of which there are three in the plant. Between three or four thousand pounds weight are then conveyed by means of wheelbarrows to the furnace. If the turnings appear to contain a high percentage of zinc, due possibly to the admixture of extruded bronze, yellow brass, brazing metal and other brasses containing high zinc, copper borings are included in the charge. Besides reducing the zinc content, the copper tends to make the brass turnings heavier, and so helps to prevent them from being blown into the flue of the furnace.

Brass turnings being of a bulky nature, it is only possible to charge approximately 1,000 lbs. at a time into the furnace. As the turnings begin to melt, a flux is thrown into the furnace on top of the molten metal. The time taken to melt the complete charge is approximately 3½ hrs., although this time is considerably reduced as the furnace becomes thoroughly heated up. When the complete charge, weighing between 3,000 and 4,000 lbs., has melted, the furnace is tapped and the metal cast into pig beds or ingot moulds. After cooling, the charge is stacked on one side, numbered, and a sample taken. The sample is then sent to the laboratory for analysis, and on return of the analysis the charge is put back into the furnace and made up to either "A.B.," "F.M.," or "B.M." brass, according to whichever metal the analysis would indicate as the most suitable and economical.

"A.B." brass, *i.e.*, brass used for axle boxes, bushes, bearings and castings required in good bronze, is composed of copper, 88, tin 10 and zinc 2 per cent. As there is always lead present in the turnings, a most undesirable element in "A.B." brass, it is necessary to reduce the lead to below 1.5 per cent. "B.M." brass is used for boiler mountings and castings of a similar nature. It is composed of copper, 85, tin 5, lead 5 and zinc 5 per cent., and as the analyses of the turnings always show all of these constituents, it is fairly easy and cheap to bring this scrap to the exact specification for "B.M." brass. "F.M." brass is used for connecting rod bushes and is composed of copper 78, tin 8, lead 13 and zinc 1 per cent. This type of leaded brass is used for bushes using grease as a lubricant in place of white metal. After these metals have been made up to specification, they are cast into ingot moulds suitably marked and despatched to stores for distribution to the various brass foundries.

The type of ingot mould used for casting brass ingots in the initial stages was the ordinary single mould type. This entailed a tremendous amount of labour in knocking out each individual ingot. It was soon observed that this could not continue, and consequently a tipping device was evolved, set up on trestles, which provided for ten ingots to be emptied at a time, by simply revolving the ingot moulds on the trestle. This method is still in use, and is proving very satisfactory.

Brass Ingots

With regard to brass ingots, it is the aim of the plant so to increase its output that the use of scrap metals in brass foundries will be eliminated. The use of an ingot having a guaranteed analysis must be preferable to the use of promiscuous scrap.

Brass ingots properly made offer the following advantages to the foundryman. Uniformly known contents, full value, low shrinkage, and low handling costs. There is no way of ascertaining the value or quality of scrap except by melting the whole lot and analysing the crucible or charge from the reverberatory furnace as the case may be. The price of ingot metal must be below that of virgin metals. The melting loss in using brass ingots must be less than that existing with the use of scrap. The exposed surface per unit content is less in the first place and there will be less surface oxidation. In the second place the foundryman will not have to melt unnecessary dirt or dross. Since he knows what each pot contains at the start, the enriching or cutting down is absolutely under his control. Ingot metal properly melted means quick heats, low melting ratios, freedom from gas and a low melting loss.

OTHER METALS RECLAIMED

Lead

Quantities of scrap lead are from time to time reclaimed, the method being similar to that used for white metals. Usually the analysis of the reclaimed lead is such that it can safely be used in the making up of C80 and P80, and is generally used up in this manner, in place of using virgin lead.

Zinc

A small amount of scrap zinc is reclaimed as it becomes available. It is melted in a cast-iron pot, and, due to its volatile nature, the temperature is kept as low as possible, *i.e.*, at round about 400 deg. C., which is about the melting point. The method of melting is to collect in the melting pot approximately 300 to 400 lbs. of molten zinc. The surface is then covered with flux and the scrap zinc immersed below the surface, piece by piece. Very little volatilisation takes place providing the temperature is controlled. More flux is then added and thoroughly stirred in. The zinc is then cast into ingot moulds and subsequently used in making up various brass alloys to specification.

Aluminium

Scrap aluminium is reclaimed with the use of "Astra Alu Flux." An ordinary reverberatory furnace is used for this purpose. The method adopted is first to melt whatever scrap is available, which is free from magnesium, thus forming a molten bath of metal, the flux being introduced while the metal is melting. When this metal has melted, additional flux is added to provide a more adequate cover. Any scrap aluminium containing magnesium in its composition is then plunged beneath the surface of the molten metal. This method prevents the magnesium from igniting and prevents undue melting loss. Care has to be exercised, however, that no overheating takes place, otherwise the magnesium is liable to ignite and cause a serious explosion, with possibly total loss of the metal in the furnace. With care the melting loss should be kept to approximately 7 per cent. It is possibly unnecessary to point out that in dealing with aluminium-magnesium alloy, care in melting is absolutely essential. The reclamation of this material is, therefore, not recommended to the inexperienced.

Fluxes

The common fluxes, such as glass, salt, charcoal, borax and sal-ammoniac, were used in the reclamation plant until a few years ago, when two proprietary fluxes were tried out and proved very efficient. The common fluxes, however, have their drawbacks.

Glass, for instance, merely provides a cover for the metal, and as glass requires a high temperature before melting, it means that the cover arrives late, thus allowing oxidation to take place before the glass melts.

Salt also provides a cover, but attacks the crucible or furnace lining, besides forming a volatile zinc chloride when used for brass. It also has no degasifying influence.

Charcoal, although providing a deoxidising influence, permits gas absorption, which is primarily the cause of porosity, and is therefore not used for melting purposes. It is useful, however, in the ladle or crucible in assisting to provide a reducing atmosphere.

Borax was not much used, as it forms a viscous slag, and therefore causes loss of metal besides having no effect on cuprous oxide. It also contains a high percentage of water, and as a chemically acting alkali it has a corrosive influence on the life of the crucible or furnace lining.

Sal-ammoniac cleanses but does not (in the writer's opinion) provide sufficient penetration.

Proprietary Fluxes

"Astra Metal Flux" used for brass and copper has proved the most efficient flux for the purpose yet experienced in the plant. This flux makes a complete cover for the metal during the melting process, thus reducing melting loss through oxidation. The slag remains fluid and so prevents metal from remaining in suspension. It keeps furnace and ladle clean and also reduces the quantity of slag in the furnace. It does not attack the furnace lining or crucible. In the manufacture of brass and copper castings it has proved useful in the elimination of porosity and improvement in mechanical properties. It will be seen from the above that the writer is wedded to the idea of using fluxes for use in non-ferrous founding; he is, for the simple reason that it pays.

Mixed Brass and White Metal Turnings

As has already been stated, the furnace for dealing with this class of material proved to be unsuited to tackle the job. The writer thereupon commenced experiments. From the initial experiments it was evident that the problem to be overcome was the necessity of seeing that the white metal left the brass turnings the moment it melted. This principle was established by using an ordinary moulder's sieve over a flame, into which some mixed turnings were placed, the sieve being moved backwards and forwards until all the white metal had fallen through. A rectangular sieve was then made, the frame being of angle iron, and the mesh of heat-resisting wire $\frac{1}{16}$-in. mesh. The furnace used was the one ordinarily employed for treating white metal dross. The sieve was provided with small wheels which ran on two pieces of angle iron, placed in the furnace at right angles to the fire box. Daily, for more than a month, this contrivance was worked by being pushed backwards and forwards by hand, and observations taken. The problem which arose from the experiment was that created by dirt and small particles of brass which percolated through the sieve and fell on the floor of the furnace. This trapped the white metal and would not allow it to flow out of the furnace. A smaller size mesh, *i.e.*, $\frac{1}{32}$ in., was tried in an effort to eliminate the trouble, but failed because of this small mesh taking on a film of oxide, thus preventing anything from falling through. It was then decided to sieve the turnings before putting them into the furnace. Satisfactory results were then observed.

It was then further decided to design a furnace for dealing with brass and white metal turnings, and a design was arrived at on the lines of a reverberatory furnace. An oscillating sieve was provided for and extended from one end of the furnace to the other, with a hopper for receiving the turnings at the end where the fire box was situated. A pyrometer was inserted in the roof of the furnace in order to control the temperature at the melting point of white metal. This furnace was put into operation, and after the usual teething troubles, commenced to give good results.

There still, of course, remained the problem of sievings which still contained brass and white metal. It was eventually decided that these be sold and a fair price was obtained through public tender. A test was carried out between April 24 and 28, 1933, that is, five working days. A representative sample of turnings was taken and gave the following results:—2,700 lbs. of brass turnings were recovered entirely free from white metal, simultaneously with 5,180 lbs. of white metal, with an average tin content of 72 per cent. The amount of coal used was 750 lbs., the furnace being worked by a labourer, specially trained by the author for the purpose.

In starting with this furnace in 1933 a vast accumulation of mixed turnings had to be dealt with, and approximately 92 tons of white metal were recovered. In 1934, 62 tons; 1935, 57 tons; 1936, 36 tons; and 1937, 56 tons were recovered. No record was kept of the brass recovered, but it would be in proportion to that obtained in the test above quoted.

The Belman Process

In 1937 it was decided to discontinue the separation of brass and white metal turnings by this method, but in 1940 a new process was evolved by two railway officials, Messrs. Bell and Manken, and duly patented. As in the previous method already mentioned, the turnings after the extraction of iron and steel by means of a magnetic separator have to be sieved through a fine mesh sieve. A quantity of the material is then placed in a wire mesh rectangular basket and immersed in a bath of hot oil, the temperature of the oil being maintained at 326 deg. C. The flash point of the oil used is 343 deg. C., so that the operator has 17 deg. margin. CO_2 fire extinguishers are provided in case the flash point is accidentally reached. When the mesh basket containing the mixed turnings has been in the oil for 2 min., it is removed and placed on a jolter conveniently situated. Jolting takes place, the white metal percolating through into a container which is an integral portion of the oil bath. When sufficient white metal has percolated through into the container, the oil becomes displaced. The white metal is then tapped into an ingot mould. The brass turnings are removed from the mesh basket and the operation repeated.

Conclusion

In establishing a reclamation plant for non-ferrous metals, a new South African industry came into being, as formerly, most of the scrap metals mentioned in this Paper were exported overseas, for treatment there.

To illustrate the steady progress of the reclamation plant at Pretoria, it may not be out of place to quote how the output of reclaimed metals has steadily increased since its establishment in April, 1932. For the eight months of 1932, 525 tons of various metals were reclaimed, made up to specification, and sent to the Stores Department; this figure was increased to 1,446 tons in 1933, since when steady progress has been made, resulting in a total of 2,897 tons being attained in 1941.

The value to the Administration has been considerable, and it can be imagined how important a metal reclamation plant is in ordinary circumstances, not to mention war conditions.

The author, in taking over the plant in 1932, realised that the work was of a specialised nature, and applied the principle of specialisation to the staff under his control.

The remarkable expertness that ensues from specialisation is well known. It springs from the cultivation of a limited field, mastered thoroughly with the utmost attention to details. The consequent extremely intimate familiarity with every aspect of the subject develops subconsciously an ever-ready ensemble of essentials. The worker is guided, as it were, instinctively. With unerring certainty he avoids all futile labour and completes his task, both with consummate skill and impressive rapidity. Indeed, in the logical application of this principle of specialisation lies the secret behind those outstandingly high efficiencies achieved by large successful organisations, in both industry and commerce, throughout the world.

Much still remains to be done in the field of metal reclamation on the South African Railways, and it is the author's hope that development will continue to such a stage that the South African Railways will be giving a lead to other railways in this important phase of engineering.

West Riding of Yorkshire Branch **Paper No. 792**

Factors Influencing the Fluidity of Cast Iron

By G. BURGESS* (Associate Member)

Fluidity is defined as "the property that metals have of flowing freely and so of filling readily the cavity of a mould," in a Paper entitled "The Fluidity of Molten Metals," presented by Desch to the Sheffield Branch of the Institute in 1921, and covers that property of cast iron and metals in general, which has been variously referred to as "flowing-power," "castability," "life," etc. The unwillingness of foundrymen to use the word "fluidity" arises from their desire not to be confused with the old and now obsolete scientific definition of fluidity which was the reciprocal of the coefficient of viscosity and was therefore a physical constant. Fluidity as it is known by the foundryman is covered by the much wider definition as given previously, and which is the resultant of several factors, and it is this wider definition which is to be considered in this Paper.

That the actual viscosity of the metal plays a very small part towards the final fluidity was shown by Desch in the Paper. In it he described methods of testing the viscosity of various non-ferrous metals by means similar to those used for lubricating oils, etc. It was found impracticable to apply these tests to cast iron and steel on account of their high melting points, but probably it can be assumed that they will follow the same rule as the non-ferrous metals. The result of these tests are summarised as follow:—"It was sometimes thought that metals were rather sluggish—watching a molten metal flowing, it seemed rather sluggish; but when it came to measuring the true viscosity it was found that most metals were only from two to three times as viscous as water."

He also described a form of spiral test used by Saito and Hayashi, two Japanese workers at the University of Kyoto in 1919, to determine the differences in fluidity of various metals and alloys. This test was later accepted in America as the standard fluidity test for cast irons and non-ferrous metals. A form of this test is also in everyday use at the foundry to which the author is attached, the difference being that the Japanese and American spirals were run from the outside end of the spiral and in the case of the Japanese spiral, included a riser in the centre, whereas the spiral used personally and shown in Fig. 1 is run at the centre and has no riser. As will be seen, the fluidity of the metal is directly proportional to the length of the spiral, which is measured in centimetres. This figure is the resultant of a number of factors which, broadly speaking, are:—Temperature; composition; amount of oxide skin; and viscosity and surface tension.

Influence of Temperature

Temperature, both with metals and liquids in general, is undoubtedly the greatest factor affecting the fluidity of cast iron. It is obvious that the nearer the freezing point of the metal, the more difficult it will be for it to flow, so that the greater the amount of superheat on the metal, the higher the fluidity. Whether there is a limit to this statement in the high temperature regions would be difficult to say, but for the range of temperatures produced by ordinary cupola melting, this is certainly true. The temperature of the metal should not be regarded as an absolute indication of good fluidity when this is high, and poor fluidity when it is low, as in certain classes of metal, the fluidity is often drastically altered by small changes in composition.

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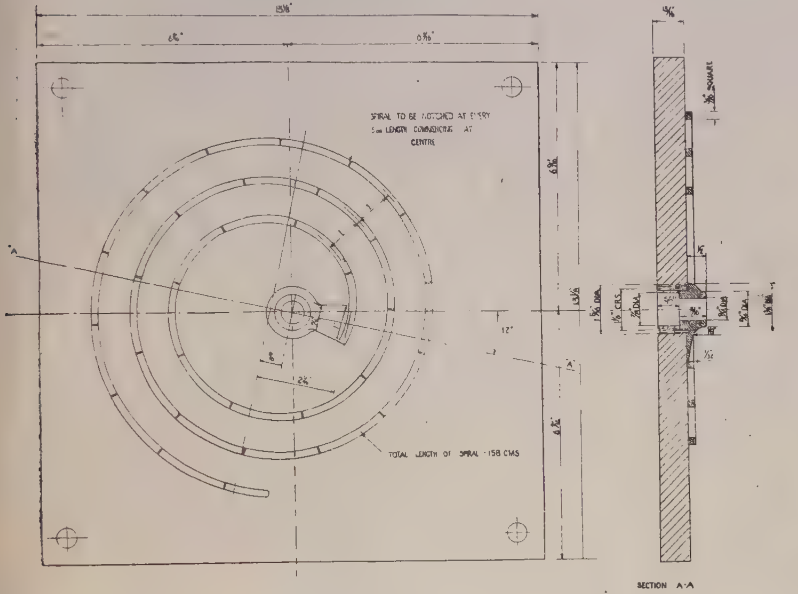
SPIRAL TO BE NOTCHED AT EVERY 5 cm LENGTH COMMENCING AT CENTRE
TOTAL LENGTH OF SPIRAL - 158 CMS
A
A
12"
2¼"
SECTION A-A

FIG. 1.—SPIRAL TEST FOR MEASURING RELATIVE FLUIDITY OF CAST IRON.

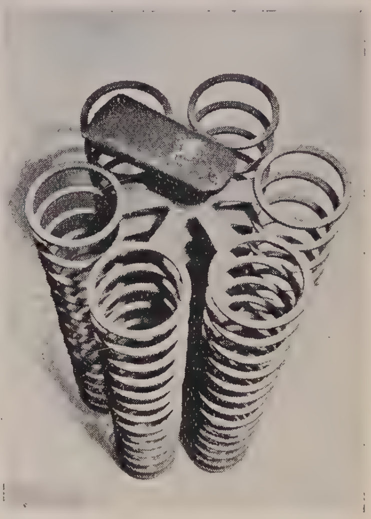

FIG. 2.—INDIVIDUALLY CAST PISTON RINGS.

The test previously mentioned is used in connection with the casting of individually cast piston rings (Fig. 2), these castings requiring a high degree of fluidity in the iron used. This is a soft iron of the following approximate composition:—T.C, 3.5 to 3.9; Si, 2.5 to 2.7; Mn, 0.6 to 0.7; S, 0.06; and P, 0.5 to 0.6 per cent. The fluidity of this metal is remarkably sensitive to changes in composition, the temperature of the metal being kept high and as constant as possible throughout the day's run on the cupola. A striking example is thus provided against the fallacy of judging the fluidity of the metal by observing it as it flows from the furnace or ladle. The normal fluidity of the metal as measured by the spiral test is approximately 75 cms., but varies from 50 to 90 cms. This is shown in Fig. 3, which shows two rings with risers, one cast in low fluidity metal and the other in normal fluidity metal. It will be seen that on the left of Fig. 4 the cavity of the mould, including the riser, is completely filled, whereas in the example on the right the ring is cast, but the riser is short run or buttoned. Both these castings were cast at the same temperature, the difference in fluidity being accounted for by difference in composition as follows:—

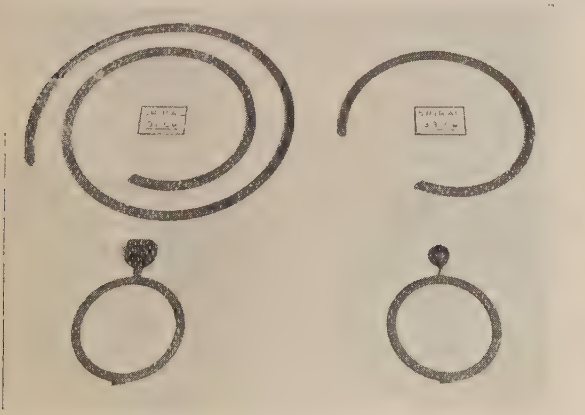

FIG. 3.—TWO RINGS WITH RISERS, CAST WITH IRONS OF DIFFERENT FLUIDITIES, AS SHOWN BY SPIRAL TESTS.

	Example 1	Example 2
	Per cent.	Per cent.
T.C	3.81	3.92
Si	2.40	2.55
Mn	0.68	0.65
S	0.059	0.062
P	0.56	0.56

The spiral test mould is cast in exactly the same way as the actual ring mould (Fig. 5) immediately after the ladle has left the furnace. The spiral casting is then knocked out and its length measured off directly by means of notches in the casting of 5 cms. intervals. This is done by placing it on a brass plate, graduated off up to 140 cms.; this figure by the way has never been reached in practice.

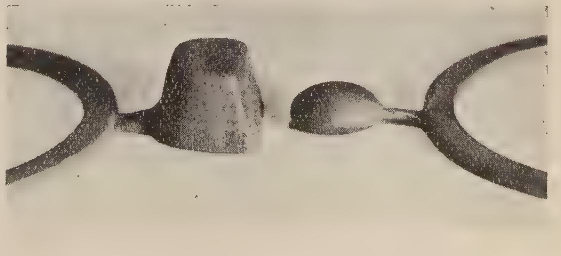

FIG. 4.—DIFFERENCE IN RISERS OBTAINED WITH IRONS OF DIFFERENT FLUIDITY.

It may be interesting here to note that fluidity on this type of metal is at a minimum when the furnace attains maximum temperature at the beginning of the day's run. At this particular point an analysis of the castings shows the total and graphitic carbon to be high—3.9 to 4.0 per cent.—probably due to the increased melting temperature causing abnormal carbon pickup from the coke, which also may be due to clean melting conditions in the furnace. As the slag volume in the furnace increases, the amount of total and graphitic carbon becomes less and the fluidity increases. It is likely that the fluidity would reach a maximum at the eutectic carbon composition, which for this iron would be 3.4 per cent. carbon. Unfortunately in practice this figure is never reached, since the castings, being small, a chilled casting would result. Also for the same reason it is not possible to say what would be the fluidity if the total carbon were below 3.4 per cent., but probably the fluidity would begin to decrease again.

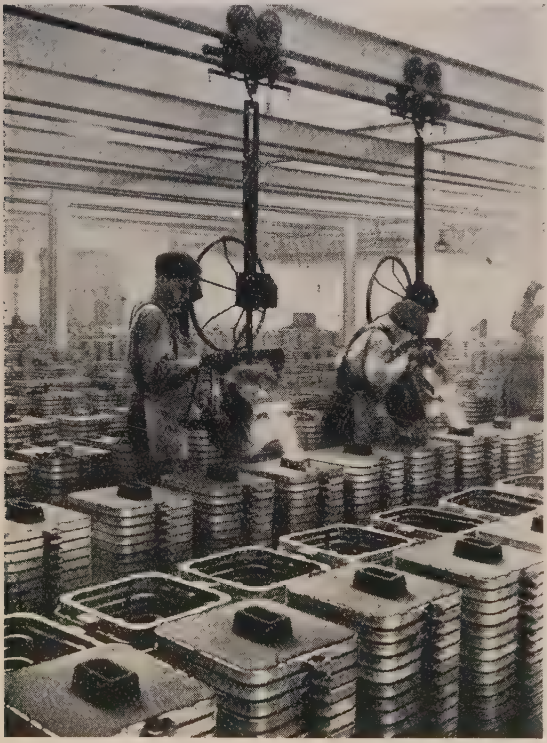

FIG. 5.—CASTING OF SPIRAL TEST MOULD EXACTLY AS ACTUAL RING MOULD.

Another possible reason for increasing fluidity as slag volume increases may be due to the presence of an increasing amount of dissolved oxides in the metal caused by a higher air-to-coke ratio due to gumming up of the coke with slag or to a lowering of the bed-height due to insufficient charge coke. The effect is similar to that produced in steel practice, where the fluidity of the metal is very important and has received considerable attention. In a Paper by Melmoth on "Electric Steel Castings" it is stated in this connection that "Certain charges, fortunately of infrequent occurrence, were found to be of such a sluggish nature, although extremely hot, that it was impossible to handle the material in shanks at all . . . By the addition of a small quantity of iron ore to the slag or of rusty steel scrap to the bath, the slag was made slightly oxidising. The viscous condition was removed. . . ." This may or may not be an influencing factor in cast iron, proof in the form of determination of oxides, etc., in the iron being a difficult undertaking.

Composition

Some remarks have already been made showing the effect of composition on fluidity, more especially with regard to the total carbon content of the iron. From experience it is thought, as has already been suggested, that other factors remaining constant, the fluidity is at a maximum with eutectic carbon composition. Eutectic carbon composition is arrived at by adding the silicon and phosphorus percentages of a given iron, multiplying this figure by 0.3 and subtracting the result from 4.3, which is the eutectic carbon content for pure iron-carbon alloy. Thus, for high-silicon, high-phosphorus irons (total percentage 3.0) maximum fluidity would be attained with fairly low total carbon, *e.g.*, 3.4 per cent. Conversely, low-carbon irons would be more fluid with high silicon and phosphorus. Low-phosphorus hematite irons in which total silicon and phosphorus would be about 1.5 per cent. would have maximum fluidity with about 3.85 per cent. total carbon.

From numerous analyses on the small castings previously mentioned, it was found that the state of the carbon had a direct bearing on the fluidity of the metal. Two charges cast into the same size of casting under the same conditions were found to be identical in analysis, including combined carbon, except graphitic carbon. The one low in graphitic carbon had normal fluidity, while the high graphitic carbon had low fluidity. Against this is the well-known fact that low-carbon irons are notoriously sluggish, which seems to be further proof in support of maximum fluidity at eutectic carbon composition. In the case of high-duty irons, which are low-carbon irons with poor fluidity, and where this deficiency cannot be remedied by changes in composition, it must be done by extra superheat.

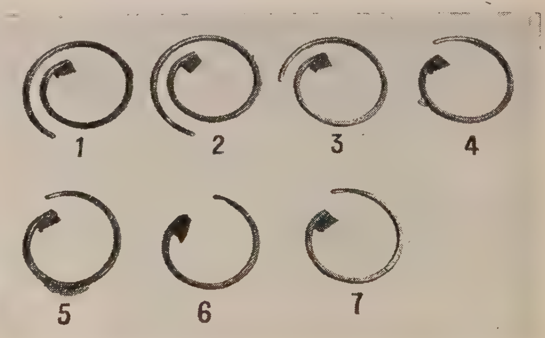

FIG. 6.—SPIRALS OBTAINED IN FIRST SERIES OF TESTS.

Though silicon and phosphorus exercise a direct bearing on fluidity, if only by their influence on the amount and state of the carbon content, yet it has been suggested that silicon increases fluidity. This statement the author believes only partly true, in so much as it affects the eutectic carbon composition; beyond this a further increase in silicon would probably cause a decrease in fluidity due to causing an increase in graphitic carbon. This theory is borne out in practice. Another fact which leads to the mistaken idea of silicon increasing fluidity is that high silicon irons melted in the cupola attain a greater amount of superheat than low-silicon irons similarly melted. This increase in fluidity, then, is due to extra superheat and not to higher silicon. This fluidity is very often also non-existent, being merely apparent on account of the extra superheat.

Phosphorus and Sulphur

It has been well known for a number of years that high-phosphorus irons were more fluid than irons lower in phosphorus. As a result of this property, stove plates and small-section intricate castings not requiring a high degree of strength were cast in high-phosphorus iron, to ensure a sharp reproduction of the mould. In addition to the reasons already given for this increase in fluidity is the more important one of the lowering of the freezing point of the iron, thus enabling a high-phosphorus iron to flow further before solidifying than a low-phosphorus iron cast at the same temperature. In cupola melting this useful property of high-phosphorus irons is very often not utilised to its full extent, since high-phosphorus irons are easier to melt than those with low phosphorus. As a result, the high-phosphorus metal passes more quickly down the furnace and does not gain as much superheat, so that the fluidity gained by higher phosphorus is lost by lower casting temperature. For this reason the use of small high-phosphorus scrap in the cupola is to be avoided.

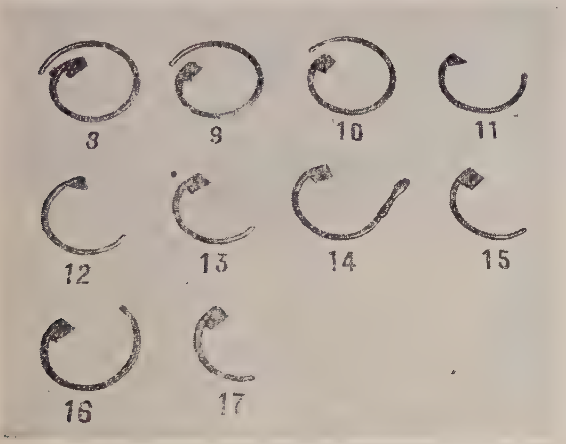

Fig. 7.—Spirals obtained in Second Series of Tests.

The relatively small percentage of sulphur usually found in cast iron will not greatly affect the resultant fluidity of the cast iron, but it has been said that sulphur decreases fluidity. In view of the other bad qualities attributed to sulphur, this is probably the case, although it will probably be possible to offset this by a proper sulphur-manganese balance. It has not been possible to say from experience just what effect sulphur and manganese have on fluidity, since both these elements are kept more or less constant for obvious reasons. The sulphur being as low as possible—0.1 per cent. maximum and manganese 0.6 to 1.0 per cent. in the irons under observation.

Manganese and Fluidity

In the case of manganese, it was noticed that this element seemed to increase the trouble already shown, namely, short-run risers, in the small individually cast piston rings. For this reason it was never allowed to exceed 0.7 per cent. Against this is the fact that manganese has a pronounced effect on the oxide-skin formed on the surface of the metal. A high-manganese iron (0.9 to 1.2 per cent.) will exhibit a very lively surface showing "flowering," as against the steady, thickly skinned surface of low-manganese irons. Also, certain high-manganese steels show a very marked increase in fluidity over the ordinary carbon steels used in steelfoundry practice.

Oxide Skin

The amount of oxide skin on the surface of the metal in the ladle is a good indication of the resultant fluidity of the metal. In many cases this is the only indication that the ordinary foundryman has, where temperatures are not taken and where the same class of metal is run every day. The action of this oxide skin is best seen by observation of metal like aluminium, where the oxide film on the surface of the metal is so tenacious that the metal underneath has literally to force its way through, when pouring is commenced. It can also be seen by a consideration of the flow of the metal in the spiral mould.

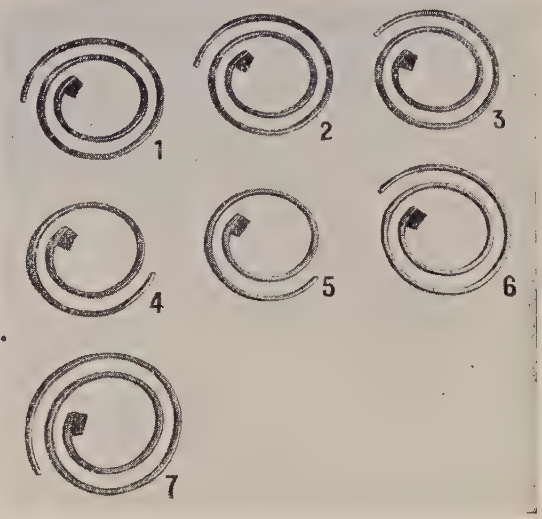

Fig. 8.—Spirals obtained in Third Series of Tests.

If the flow is recorded as a series of small individual thrusts, the metal can be visualised as having to force its way at each thrust, through a layer of oxide skin which increases in thickness as the metal begins to set, till a point is reached when this film is so thick that this becomes impossible. This theory is substantiated by the fact that many spirals when examined are found to have a small bead of metal at the end, which has forced its way through the final oxide skin and then solidified. It is also interesting to note that many spirals have their corners rounded, and even become flattened towards the end of the spiral. The extent of this rounding or flattening seems to depend on the composition of the metal, being more noticeable on low carbon irons.

Viscosity

This has, of course, a direct bearing on fluidity, but since it has not been fully explored, for the purpose of this Paper, together with surface tension, it has been regarded as a constant.

Having outlined the factors influencing the fluidity of cast iron as observed from practical experience, it was thought it would be interesting to try and justify these by experiment. Several difficulties arose, however, the first and main one being the enormous number of variables. Then came that of the necessity for accurate temperature measurement. This could not be done with an optical pyrometer, which was the only instrument available, so that the temperatures given later cannot be regarded as absolute, but merely comparative. With regard to composition, each of the main elements, carbon, silicon, sulphur, phosphorus and manganese, was open to investigation at various percentages, the remaining four elements remaining constant. In addition to these were the alloying metals, nickel, chromium, molybdenum, etc., but such a large quantity of different compositions were required that it was decided to narrow these down to three compositions:—(1) A low silicon, medium carbon, medium phosphorus iron, such as is used for fairly large castings; (2) a low carbon iron such as is used for high-duty castings, and (3) a normal foundry iron, high in phosphorus, such as is used for light jobbing work, where no particular strength is called for, and fluidity is very important.

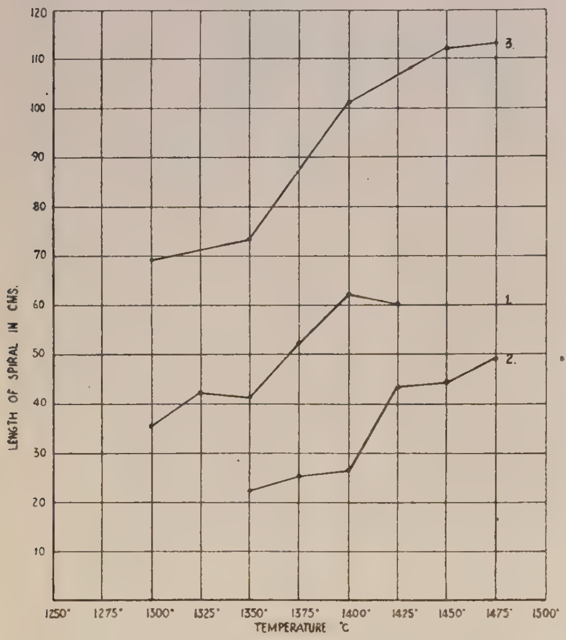

FIG. 9.—GRAPH SHOWING RELATIVE FLUIDITIES OF THREE MAIN IRONS INVESTIGATED.

The results of the following experiments, therefore, are not meant to be regarded as absolute values, but are merely to show the relative fluidities of three widely different compositions at different temperatures.

The form of fluidity test used was a modification of the spiral test already described. The original spiral mould was first tried, but with some of the irons in use, particularly the low-carbon ones, it was found to give very low results. Another pattern was therefore made, having the sections increased to $\frac{9}{32}$ in., the ingate to $\frac{7}{32}$ in. tapering to $\frac{1}{8}$ in., where it entered the spiral, and the downgate to $\frac{13}{16}$ in., the other dimensions remaining the same. For the sake of convenience in moulding, the head was also shortened to 3 in. from 4½ in.

A 150 lbs. melt of the first iron was made in a crucible furnace, the charge was 100 per cent. scrap. The resultant metal gave the following analysis:—T.C, 3.14 per cent.; Si, 1.17; Mn, 0.51; S, 0.125; P, 0.34; Ni, 0.16, and Cr, 0.23 per cent. The small percentages of nickel and chromium were incidental and not intended constituents. Spirals were then cast from this metal, which was round about 1,500 deg. C. at 25 deg. intervals from 1,475 deg. C. to 1,300 deg. C. The method of doing this was to take about 5 lbs. of metal in a sample spoon holding from 8 to 10 lbs., set the optical pyrometer at the temperature required, sight it on the surface of the metal in the spoon, allow the metal to cool to the required temperature, then quickly cast the spiral. Fig. 6 and the table overleaf show the results.

Spiral No.	Temp. Deg. C.	Length Cms.
—	1,475	Bad mould
—	1,450	,, ,,
1	1,425	60
2	1,400	62
3	1,375	52
4	1,350	41
5	1,325	42
6	1,300	35

Then 1 lb. of ferro-silicon in lump form was added to the remaining metal, and another spiral was cast at 1,400 deg. C., the length of which was 40 cms. This is 22 cms. less than the spiral cast without silicon at the same temperature. The analysis of this iron was now as follows:—T.C, 3.14; Si, 2.05; Mn, 0.66; S, 0.106; P, 0.30; Ni, 0.16, and Cr. 0.23 per cent.

Using this iron as a base, an addition was made of 12½ lbs. of refined pig-iron (approximately 10 per cent.), and 12½ lbs. of steel scrap. The analysis now became:—T.C, 2.75; Si, 2.10; Mn, 0.63; S, 0.107; P, 0.40; Ni, 0.20, and Cr, 0.21 per cent. The temperature was again raised to 1,500 deg. C., and a set of spirals cast exactly as before with the results shown in Fig. 7 and as below:—

Spiral No.	Temp. Deg. C.	Length Cms.
8	1,475	49
9	1,450	44
10	1,425	43
11	1,400	26
12	1,375	25
13	1,350	22
—	1,325	Bad moulds
—	1,300	,, ,,

Then ½ lb. of lump ferro-silicon was added and a spiral cast at 1,425 deg. C., but the ferro-silicon must not have dissolved, since on analysis the silicon was only 0.12 per cent. higher (2.22 per cent.), and anyway the spiral as will be seen from Fig. 7 is useless on account of a bad mould.

Next ½ lb. of nickel shot was added to the metal, this addition made the total percentage of nickel 0.79 per cent. A spiral was cast at 1,425 deg. C., the length of which was 20 cms. It was thought that this shortening of 23 cms. compared with the spiral of 43 cms. in the almost nickel-free iron, may be due to the fact that it was poured by a different man, who probably did not get the metal into the mould quickly enough. As there was a shortage of moulds, however, it was decided to continue, so a further ½ lb. of nickel shot was added which now brought the total percentage to 1.42 per cent. Another spiral was cast at 1,425 deg. C. by the usual man, but this spiral was only 31 cms. compared with 43 cms. for 0.2 per cent. nickel. Although no definite conclusions as to the behaviour of nickel can be made from these two results, they seem to indicate that even if nickel does not actually reduce the fluidity of cast iron, it certainly does not cause any marked increase, as is sometimes claimed.

The remaining metal was now poured from the furnace into a shank containing ¾ lb. of powdered soda-ash, and another spiral was cast. This, however, was faulty, being only 17 cms. in length, as it was not found possible completely to clear the surface of slag, and some of it reached the mould. The analysis of the metal was:—T.C, 2.75; Si, 2.22; Mn, 0.63; S, 0.079, and P, 0.42 per cent.

Another 150 lbs. melt was now made, again with 100 per cent. scrap. A spiral was cast at 1,475 deg. C., the length of which was 102 cms.; a phosphorus estimation was made on this metal, and was 0.51 per cent. phosphorus. To this metal was then added 1½ lbs. of ferro-phosphorus, and a series of spirals was cast at various temperatures as before. The iron was of the following composition:—T.C, 3.36; Si, 2.45; Mn, 0.70; S, 0.076; P, 0.74; Ni, trace, and Cr, 0.17 per cent.

The results of these spirals were as shown in Fig. 8, and tabulated below.

Spiral No.	Temp. Deg. C.	Length Cms.
2	1,475	113
3	1,450	112
—	1,425	Bad mould
4	1,400	101
5	1,350	73
6	1,300	69

On account of a shortage of moulds, the spirals corresponding to 1,375 and 1,325 deg. C. had to be omitted. A further 1½ lbs. of ferro-phosphorus was added to the remaining metal and a spiral cast at 1,450 deg. C., the length of which was 120 cms. This metal had 1.25 per cent. phosphorus.

Although these experiments were very limited, they substantiate the remarks already made regarding the influence of temperature and composition on the fluidity of cast iron.

A graph (Fig. 9) was made to show the relative fluidity of the three main irons investigated; this shows that to obtain the same fluidity from irons (1) and (2) it would be necessary to give iron No. 2 approximately 100 deg. C. extra superheat. Also, that iron No. 2 cast at 1,475 deg. C. is not as fluid as iron No. 3 cast at 1,300 deg. C. These results, although not intended to be regarded as absolute values, show the very wide variation existing between irons of different compositions. It is also interesting to note that the difference in fluidity due to temperature variation does not follow a straight line on the graph, but falls off very rapidly in the case of iron No. 2, becoming steadier in iron No. 1 and still steadier in iron No. 3, in which case it occurs over a range of 50 deg. C. This peculiarity may be due to a sudden lessening of the fluidity due to the formation of primary austenite particles in the liquid metal, as this occurs about the required temperature on the equilibrium diagram. Another explanation is that, owing to waiting for the metal to cool in the sample spoon, a heavier oxide film is formed on the metal cast in the lower temperature range.

In conclusion, the author thanked the directors of Messrs. Hepworth & Grandage for their permission to publish facts relating to the production of single-cast rings, and also for their permission to carry out the experimental work.

DISCUSSION

MR. G. W. NICHOLLS asked whether the author instituted sand control in his spiral tests?

MR. BURGESS replied that the sand used was controlled at about 3.5 per cent. moisture, 10 lbs. bond strength, and 32 permeability number. Moreover the moulds were roughly of the same density.

The BRANCH-PRESIDENT (Mr. F. Oldershaw) asked were these moulds made in green sand or dry sand? He asked because in the illustrations he noticed certain places seemed a little thickened, and he wondered whether it would be better to standardise on the dry sand mould to avoid any swelling owing to pressure?

MR. BURGESS said that in America tests were made as to whether they should be in dry sand or green sand, and the conclusion was reached that it was immaterial. The swellings noted in the illustrations were caused by photographic technique.

MR. H. FORREST, supplementing the author's observations in regard to the fluidity test, said the moulds for the tests had been made from a pattern plate fitted to a moulding machine. Each day two or three stacks were made, and the process was quite standardised. The type of sand used was exactly the same as the process sand, and the moisture and degree of running did not vary.

Excessive Blast

The CHAIRMAN asked whether the author could explain more fully how excessive blast and oxygen affected the fluidity?

MR. BURGESS said it would induce a definite decrease in fluidity.

The CHAIRMAN added that excessive blast would lower the carbon and consequently reduce the fluidity. With 3.3 to 3.4 per cent. carbon there should be no sluggishness, and excessive oxygen had an influence on fluidity owing to the wetting propensities in the surface tension of the smaller globules. He agreed there was no means of checking it because when it was solidified the effect was gone.

MR. FORREST pointed out that it was often noticed in general foundry practice that where there was an excessive amount of air going into the cupola, the iron went off condition very quickly and lost its good casting properties. It was definitely attributable to lack of fluidity. The reason was, he thought, the high oxygen content of the iron. It was a fact that irons were influenced by the amount of oxides present, and probably that would be borne out by the experience of most foundrymen when they made a particular batch from certain types of pig-iron which were found to give poor results. He believed that was related to the melting practice of the particular iron, and was very often confined to certain refined irons, due to the expedients used in some cases to obtain these carbon refined irons.

The CHAIRMAN, agreeing, said the metallurgist would insist it was impossible to have more than a certain amount of excess oxide in an iron because there were enough elements to nullify it, but still founders do sometimes get an iron which has something about it which one cannot explain, and he thought it was quite possible to have that difficulty in the liquid state and yet not be able to trace it in the solid iron.

MR. FORREST pointed out he was not referring to iron oxide. He thought it was the silica which was oxidised, and low fluidity results. Possibly it was due to a formation of silicates in the melt rather than to oxidation of the iron.

Standardised Conditions

MR. OLDERSHAW asked whether there was a definite head pressure on the bush—was it of the standard pressure type variety? He asked this because he felt a point which influenced fluidity was that of the height from which it was poured. Did the author vary his pouring or was it constant?

MR. BURGESS said he used a ladle bowl set about 1 in. above the bush, and it was poured as quickly as possible so that there were no temperature variations.

MR. FORREST added that the spiral test was carried out very quickly. It was knocked out before the bush was set and a quick estimation of conditions was established.

MR. W. G. THORNTON referred to the fact that all the examples given were pot-melted, and asked whether it made any difference if some of them had been cupola melted.

MR. BURGESS said that probably there would be a material increase in the fluidity.

Steel Problems

MR. W. PARKER said he had lately been dealing with a problem involving the fluidity of steel. The steels had been the same temperature and he should imagine that, if they were to run like the spiral tests, the difficulty might be overcome. In his work the sand had reached to as low as 2 per cent. moisture, and a permeability of about 150, but they had to increase the latter to about 200. Then, by keeping the moisture low and bond strength high, the metal ran perfectly, and yielded very clean castings. It seemed, he thought, to suggest that the permeability figure helped with fluidity.

The CHAIRMAN asked whether there was an air vent in spiral tests, or did it terminate in a dead end? If there was no vent, then there may be a "jumping" effect. Some form of outlet would help in the formation of a better spiral.

MR. FORREST said there was no vent, as he required to test every charge and establish the same conditions for proper control. No special sand was purchased. It was virtually a facing sand and there was no coal dust incorporated.

Influence of Aluminium on Fluidity

The CHAIRMAN then inquired whether any aluminium was used to help in extending fluidity.

MR. BURGESS said that aluminium would be definitely harmful to the metal, as it tended to lower rather than increase the fluidity unless it was highly oxidised.

The CHAIRMAN thought an addition of about 2 ozs. of aluminium per ton had a beneficial influence on fluidity. The aluminium was changed to alumina, and he had found it did improve fluidity.

MR. FORREST said, personally, he would not like to advise anybody to use aluminium for this purpose. He recalled a sample of a "cure-all" specific which he was once persuaded to use, and he obtained a cast ring literally full of holes. The material was part aluminium dust and part silicon, and ever since then he became convinced that aluminium was unsuitable except for the bigger type of castings.

The CHAIRMAN agreed that aluminium was a potential cause of trouble, but he thought it did improve fluidity, and it was a case of using it, if at all, with all factors in mind.

High Manganese and Pinholing

MR. FORREST said a remarkable thing occurred when the manganese content was high. On one occasion, he recalled, he increased the manganese content, which improved the casting, but when it was increased still further, pinholing resulted. There was evidently a definite point of relationship between manganese and silicon at which there was this very fine pinholing, and it was necessary to avoid reaching that point.

MR. BURGESS gave another illustration, in the case of pistons, of faults due to lack of fluidity, and he showed by blackboard sketches a shrink-hole and a small "bead" or pellet of iron which, he said, was found to be due not to the metal, but probably to poor fluidity.

The CHAIRMAN pointed out that such "beads" could often be attributed to the phosphide eutectic in the metal being squeezed into that pellet formation.

MR. BURGESS said that in the case cited a very low phosphorus iron was used, and it was felt that it was quite definitely a fault related to insufficient fluidity.

MR. THORNTON favoured the theory that the beading was due to the carbon being too low in relation to the low phosphorus. Thus it became a question of composition rather than fluidity.

MR. NICHOLLS said he agreed with the author's view that it was most likely due to lack of fluidity. Even if the metal was slightly oxidised on the skin, a "bead" of iron can appear.

MR. BURGESS pointed out that the "bead" was not always there.

MR. FORREST said that, with a higher domestic scrap percentage in the charge, the carbon content was lowered and the eutectic composition was approached, resulting in trouble. If there was a progressive decrease in the carbon content due to dilution, the eutectic composition is finally approached, and then trouble ensued. Experience had shown how to avoid reaching that point.

MR. BURGESS said he had carried out some fluidity tests using the centrifugal method of casting, and found a cavity or "dimple" on the outside of the ring when the fluidity of the metal was low, but it disappeared when fluidity was increased.

MR. FORREST said that certain brands of pig-iron appeared to cause more trouble in that respect than others, but it was not necessarily so. One cause was holding the metal too long in the cupola. Although no actual carbon pick-up occurred, it did have an influence on the "life" of the metal.

MR. BURGESS pointed out that the fluidity might not be the cause of these defects, but, if it was low, trouble was certain. There was no doubt that there was a definite falling off in fluidity under war conditions, quite probably due in some measure to reasons of this kind.

Vote of Thanks

Thanks to Mr. Burgess—and also to Mr. Forrest, who had been associated with the tests—were carried unanimously, on the motion of MR. G. C. TURNER, seconded by MR. F. SQUIRES.

MR. BURGESS, in responding, voiced his thanks to Mr. W. Jones and Mr. W. L. Bolton, two members of the Branch from the same firm, for assistance they had given in the work involved in preparation of the Paper.

Hot Tear Formation in Steel Castings

AUTHOR'S REPLY TO DISCUSSION ON PAPER No. 774

MR. CHARLES W. BRIGGS wrote, in reply to the discussion, that he was very greatly indebted to Mr. Fassotte for his review and remarks regarding the Paper. It was indeed an honour to have Mr. Fassotte introduce the Paper to the Institute; his knowledge of the fundamentals of steel casting production is well known and widely appreciated. The writer was very much interested in the remarks of Mr. Fassotte regarding "the British foundry which had a run of hot tears at the inside of a flange at the end of a particular casting." The writer has been in contact with the same type of hot tear located in the flange section of high pressure fittings, at several foundries in the United States.

Seven Points

The seven points of comparison which the British foundry had employed are interesting, and it is believed that some comment could be made on these points:

(1) Both basic and acid steels were tried. Generally speaking, the behaviour was the same, though results with basic steels were slightly better.—*Comment*: This is in line with reported results.

(2) The carbon range of the steels used between 0.2 and slightly above 0.3 per cent. Tears were equally persistent with all the carbon contents.—*Comment*: The Paper showed that there was little or no difference between 0.20 and 0.35 per cent. carbon steels. Studies should have been made on steels of 0.10 to 0.15 carbon contents.

(3) The sulphur variation in the steels employed was between 0.02 and 0.03 per cent., with no noticeable difference in results.—*Comment*: Steels of sulphur content under 0.02 should be compared with steels of sulphur content of about 0.05.

(4) The phosphorus variation between 0.02 and 0.04 per cent. gave no continued different behaviour.—*Comment*: None would be expected in this range.

(5) The steels were examined for non-metallic inclusions without yielding any information. Sections of defective castings have, however, been sent to the author, and he may have a different opinion on this point.—*Comment*: In this connection, the author repeated a paragraph of the Paper which, he thought, explained fully the manner in which inclusions should be viewed: "Remarks on inclusion types should be looked upon only as trends that may exist, for the other factors that are discussed in the Paper require greater consideration. The use of a certain type of deoxidiser is not going to make the steel relatively resistant to hot tearing."

(6) The widest practical range of pouring temperatures gave no indication that the casting temperature had anything to do with the formation of this particular hot tear.—*Comment*: Experiments in the United States with respect to the fittings showed that this was not the case, and that the degree of tearing was affected considerably. However, hot tearing was not prevented by changing the temperature of the metal as poured:

(7) Different moulding media and hardness of ramming were tried without any results.—*Comment*: This differs from experience in the United States. While the particular hot tears in question were not eliminated by changing sand conditions, the degree of tearing was changed materially.

Origin of Tears

It was noted that the British foundry attributed the reason for the hot tears to "insufficient fluid heat of metal at the moment of solidification." First of all, the degree of fluidity of the steel has nothing to do with hot tear formation. A steel cannot tear until it is solid. A lack of a supply of steel for feeding purposes may be responsible for the tear, as was shown in the Paper; however, it was found in America, in the particular case in question, that a well fed section can exhibit tears. It is also true that lack of feeding of the section aggravates hot tearing. Thus, I do not believe that the reason assigned was the correct one for explaining the hot tearing.

Valve manufacturers in the United States have had some little trouble with hot tears underneath the flanges in the ports of fittings. Many experiments have been carried on to study the influence of variations in core sand mixtures, the influence of heading and gating, and the influence of variations in ratio of flange thickness to wall thickness. It was found that by the use of certain sands a more pronounced hot tear could be found. The section could be completely fed, but hot tears still persisted even though the tears were more pronounced when the sections were not completely fed. Also, the greater the ratio of flange thickness to wall thickness, the greater is the tendency towards hot tearing. The tearing was prevented by the use of external chilling on the port area and at the fillet area back of the flange.

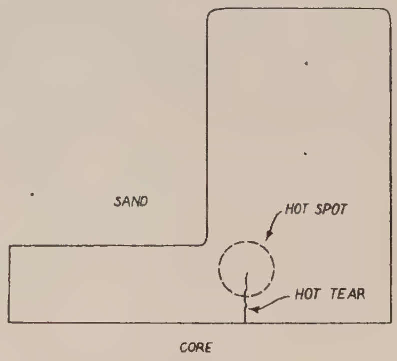

FIG. A.

It will be noted that, again, little was implied and nothing said by the British foundry regarding the stresses involved during the cooling of the casting. First, in the cooling of the flange and wall area, a pronounced hot spot will exist at the location shown in the drawing, because of the location of the fillet and the core and their effect upon the rate of heat extraction. The hot spot area will exhibit the lowest strength of a cooling section.

The design of the casting is such that the light wall section completes solidification and begins to contract before the much heavier flange section. Stresses are set up and tearing takes place in the weakest section in much the same way as was illustrated in Figs. 6 and 7 of the Paper. The sand mould assists in the tearing because it resists the normal contraction of the casting.

Responsibility of Design

Forget the drawing (Fig. A) and look at the casting. It is completely circular, both the flange and the wall, and hence is a stress-active system. Thus the design is responsible. This can easily be seen when it is realised, as shown by experimentation, that the greater the ratio of flange thickness to wall thickness, the greater is the tendency to hot tearing. The tear breaks into the port area rather than into the fillet because the stress is due more to casting design and less to mould resistance. Why is it that chilling the port area and the fillets is the practical remedy? The chills reduce the effect of the hot spot and increase the strength of the steel, since the steel at this point is at a lower temperature and hence stronger and more able to resist the concentration of stresses.

It is noted that Mr. Fassotte pointed out that resistance to contraction due to casting design and nature of moulding materials is beyond calculation. While this is true, the author believed such statements tend to make foundrymen look upon the study of stress conditions, their origin and effect, as academic and of no practical value. He was firmly convinced that if a foundryman would review the reasons for stress formation and concentration, he would find the cause of hot tearing.—This is a much more direct method than attempting to track down the contributing variables such as was done by the British foundry in the investigation.

The author wished to thank Dr. Dadswell, Mr. Salmon, Mr. Cooper, Mr. Rowe and Mr. Skidmore for their contributions to the discussion of the Paper. He agrees with Dr. Dadswell in that steelmaking is a very important part of the hot tear problem. The proper type of inclusions should be obtained, and phosphorus and sulphur should be kept to a low figure. The writer wishes to take exception to the statement by Mr. Salmon, that the Paper " provided an excellent summary of the published information on hot tear formation." The Paper contains much original information, and it is the first time that all the variables have been tied together to show their relative importance.

A Test of Hot Tear Susceptibility

In reply to Mr. Salmon's question regarding the developments of a foundry test for hot tear susceptibility, it may be said that several foundry organisations and one research laboratory in the United States are working on such a test. One test has been developed, as reported by Crafts in Reference 14 of the Paper. It is noted that Mr. Salmon desires this test to show the influence of three variables: (1) Casting temperature; (2) steel composition and method of manufacture and (3) sand strength. The writer agrees with Mr. Salmon that for any given design of casting there is an " ideal range " of pouring temperatures; however, the temperature of the molten steel has no effect upon hot tear formation, except only in the variation of temperature gradients that can be formed in the metal and in the mould when the metal is in the mould. The use of superheated steel has no effect upon the properties of the steel at temperatures directly below its solidification temperature.

Further, in reply to Mr. Salmon, high sulphur content steels will not hot tear if the stresses acting on the casting are not sufficient to cause hot tearing. It can be said of two steel castings, one of high sulphur content and one of low sulphur content under identical contraction stresses, that the higher sulphur content steel will be more susceptible to hot tear formation than will the other steel. In this case hot tear formation will depend upon whether or not the stress exceeds the mechanical properties. There is no technical information available, to the knowledge of the writer, which shows that silicon or copper in substantial percentages in steel increase the mechanical properties of the steel at elevated temperatures, over that found for carbon steels.

In reply to Mr. Rowe, who was of the opinion that not enough emphasis was placed on the influence of steelmaking on hot-tear formation, the following question is proposed: In what manner can the manufacture of steel possibly affect the elevated temperature properties of the metal? There are only two ways: (1) inclusion type and distribution, and (2) gas (hydrogen or nitrogen) content.

Poor Steel No Criterion

A discussion of inclusion type and distribution was presented in the Paper. The writer did not go into the details of steelmaking methods for producing the proper inclusion types or their distribution, as the subject was hardly the subject of the Paper. The gas content of the metal does affect the conditions of porosity, and it is known that hot tears often originate out of cavities such as shrinkage cavities, as was illustrated in the Paper. Again the writer feels that it is necessary to add that the poorest made steel will not hot tear if it is not subject to high stresses at temperatures just below the solidification temperature of the steel.

The writer disagrees with Mr. Cooper and Mr. Skidmore, that the majority of hot tears are caused by carelessness. It is believed that the responsibility of most hot tears should be placed on: (1) the designer, and (2) the foundry layout committee, for not recognising the conditions accountable for stress formation at the hot tearing temperatures and taking the necessary steps to correct these conditions during the preparation of the pattern and the moulding of the casting.

In further reply to Mr. Skidmore's questions, it is believed that hot tears form at the time of, or after, completion of solidification of a section. The writer recognises no "stiff pasty state" in the progressive solidifications of a steel casting. Also, cavities do not cause hot tears to lead out of them since hot tears need not be associated with cavities at all. However, in some cases hot tears are found to be associated with cavities, such as internal hot tears resulting from solidification contraction.

The writes appreciates the complimentary remarks of Mr. Fassotte, Mr. Salmon and Mr. Faulkner, and is very much pleased that they found the Paper valuable and interesting. The writer regrets that he was unable to present the Paper in person, as he would very much have liked to meet those who took part in the discussion and others of the British steel castings industry. He greatly appreciated the opportunity of preparing the American Foundrymen's Exchange Paper to the Institute of British Foundrymen.

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